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Draft Regulatory Impact Analysis

Control of Gasoline Volatility
and
Evaporative Hydrocarbon Emissions
from New Motor Vehicles

July 1987

U.S. Environmental Protection Agency
Office of Air Radiation
Office of Mobile Sources

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Chapter 2

In-Use Motor Vehicle Related Hydrocarbon Emissions

The primary goal of this chapter is to determine the relationship between fuel volatility and hydrocarbon (HC) emissions, which will be used later for air quality modeling in Chapter 3. Section I is more general in nature, describing the current ozone noncompliance situation. It's emphasis is on establishing the need for HC control and on identifying the seasonal and geographical extent of this need. The remaining sections of the chapter are an analysis of the effect of fuel volatility and in-use conditions on both hydrocarbon and benzene emissions, both from vehicles and from gasoline distribution systems. Consideration was given to the effect of fuel volatility and in-use conditions on hydrocarbon and benzene emissions from each possible emission source independently.

Section II presents the effect of volatility on hydrocarbon emissions from gasoline-fueled and alcohol blend-fueled vehicles and also the emissions from the gasoline distribution system. The vehicle emissions discussed are evaporative, exhaust, and refueling emissions, with the primary emphasis on evaporative emissions. The discussion on evaporative emissions presents the data upon which the evaporative emissions model was based, develops the evaporative emissions model, explains the process by which the model is adjusted for in-use conditions, and also analyzes the effects of fuel distillation properties on evaporative emissions.

Vehicle emissions of benzene, a known carcinogen, were also investigated. Work done to quantify evaporative and exhaust benzene emissions as they relate to fuel volatility is presented in Section III. Vehicle refueling is another source of benzene emissions but is not dealt with here in depth since this subject has been treated elsewhere sufficiently.[1,2]

Chapter 2 concludes with two appendices. Appendix 2-A presents a more detailed description of how the Emission Factor vehicle evaporative emissions data were broken down into their components, and how vehicle evaporative emissions were predicted based on the emission components. Appendix 2-B presents the data which the benzene analysis of Section III is based on.

I. Ozone Noncompliance Situation

A. Non-Attainment Areas

The National Ambient Air Quality Standard (NAAQS) for ozone is a concentration of 0.12 parts per million (ppm), and is attained when the expected number of calendar days per year with maximum hourly concentrations exceeding the standard is less than or equal to one. EPA determines whether an area is in compliance with the ozone NAAQS on the basis of the area's ozone design value, defined as the fourth highest daily maximum one-hour measured ozone concentration over a three-year period.* Based on 1982-84 design values, the most recent available at the time of this analysis, EPA's Office of Air Quality Planning and Standards (OAQPS) currently designates 73 urban areas** (12 of them in California) as non-attainment areas for ozone. This compares to the 54 such areas (seven in California) that were designated as non-attainment areas based on 1981-83 design values, as described in EPA's original volatility study.[3]

The analyses presented here focus on the 61 non-California urban non-attainment areas. For reasons that are described in Chapter 3, the 12 urban non-attainment areas within California were not modeled individually, although the nationwide emissions inventories presented in Chapter 3 include the state of California in the totals. These 61 areas and their associated ozone design values are presented in Table 2-1.[4] For additional information on the development of the ozone design values presented in Table 2-1, the reader is referred to the report, "Standard Metropolitan Statistical Areas Regulatory Analysis Air Quality Data Base, 1982-84."[5]

The serious nature of the ozone noncompliance situation becomes clearer when the design values in Table 2-1 are examined. Many of the 61 urban areas listed have design values of 0.15 ppm or greater. Recent air quality modeling, the results of which are presented in Chapter 3, indicates that it is very unlikely that any of the areas having design values of 0.15 ppm or greater can achieve attainment with the ozone NAAQS by the statutory deadline of December 31, 1987. In fact, in the absence of any additional programs to reduce emissions of ozone precursors, projections indicate that 40 of the 61 areas will continue to be in non-attainment status at the deadline.

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* Or the third highest from two years of data, or the second highest from a single year's data.

** Metropolitan Statistical Areas (MSA), or combinations of contiguous MSAs.

Table 2-1

61 Non-California Urban Ozone Non-Attainment Areas and Associated Design Values (ppm) [2]

Area	Design Value
EPA Region 1	
Boston Metro Area	0.19
Greater Connecticut Metro Area	0.23
New Bedford, MA	0.19
Portland, ME	0.15
Portsmouth-Dover-Rochester, NH-ME	0.13
Providence, RI	0.16
Springfield, MA	0.19
Worcester, MA	0.14
EPA Region 2	
Atlantic City, NJ	0.19
New York Metro Area	0.23
Vineland-Millville-Bridgeton, NJ	0.14
EPA Region 3	
Allentown-Bethlehem, PA	0.15
Baltimore, MD	0.17
Erie, PA	0.13
Harrisburg-Lebanon-Carlisle, PA	0.13
Lancaster, PA	0.14
Philadelphia Metro Area	0.18
Pittsburgh, PA	0.14
Reading, PA	0.13
Richmond-Petersburg, VA	0.14
Scranton-Wilkes Barre, PA	0.13
Washington, DC-MD-VA	0.16
York, PA	0.13
EPA Region 4	
Atlanta, GA	0.17
Birmingham, AL	0.15
Charlotte-Gastonia-Rock Hill, NC-SC	0.13
Chattanooga, TN-GA	0.13
Huntington-Ashland, WV-KY-OH	0.14
Louisville, KY-IN	0.15
Memphis, TN-AR-MS	0.13
Miami-Hialeah, FL	0.13
Nashville, TN	0.13
Tampa-St. Petersburg-Clearwater, FL	0.13

Table 2-1 (cont'd)

Area	Design Value
EPA Region 5	
Akron, OH	0.13
Canton, OH	0.13
Chicago Metro Area	0.20
Cincinnati Metro Area	0.15
Cleveland, OH	0.14
Dayton-Springfield, OH	0.13
Detroit, MI	0.14
Grand Rapids, MI	0.13
Indianapolis, IN	0.13
Milwaukee Metro Area	0.17
Muskegon, MI	0.14
EPA Region 6	
Baton Rouge, LA	0.17
Beaumont-Port Arthur, TX	0.21
Brazoria, TX	0.14
Dallas-Fort Worth, TX	0.16
El Paso, TX	0.17
Galveston-Texas City, TX	0.17
Houston, TX	0.25
Lake Charles, LA	0.15
Longview-Marshall, TX	0.15
New Orleans, LA	0.15
San Antonio, TX	0.14
Tulsa, OK	0.13
EPA Region 7	
Kansas City, MO-KS	0.14
St. Louis, MO-IL	0.17
EPA Region 8	
Denver-Boulder, CO	0.14
Salt Lake City-Ogden, UT	0.15
EPA Region 9	
Phoenix, AZ	0.15

The severity of the ozone non-attainment problem can also be seen when the populations of the non-attainment areas are considered. Based on 1980 census data, more than 92 million people (more than 40 percent of the nation's population) reside in the 61 urban ozone non-attainment areas outside California. When all 73 areas (including California) are considered, the total population living in non-attainment areas is about 115 million, or approximately half the nation.

This information briefly but clearly illustrates the widespread nature of the ozone noncompliance situation. In the following section, the seasonal nature of violations of the ambient ozone standard is discussed.

B. Seasonal Nature of Ozone Noncompliance

Another important perspective on the ozone noncompliance situation is the seasonal nature of violations of the ozone NAAQS. Examination of data recorded at ozone monitoring sites in non-attainment areas has revealed seasonal trends in ozone violations. As might be expected, the majority of all ozone violations occur during the summer months, when ambient conditions (i.e., temperatures and length of daylight) are most favorable to ozone formation. These seasonal trends are important in determining during what period (specific months) hydrocarbon emission reductions would be most valuable. This is an important consideration with respect to any in-use volatility control measures, as they have the flexibility to be implemented throughout the year or only during specific months. However, other hydrocarbon emission control measures, such as revisions to certification fuel specifications and test procedure, would affect vehicle design and thus represent year-round control.

As is also discussed in Chapter 3, the air quality analyses included in this study focus on the "design value day" (i.e., the date on which the ozone design values shown in Table 2-1 were recorded). Ozone air quality modeling is performed over a one-day period. (Modeling over two or three days is possible, although these models require inputs too detailed for application to the 61 areas.) The rationale for focusing on the design value day is that it represents the worst-case situation in terms of ozone compliance. If the projected ambient ozone concentration for an area, based on the conditions that existed on the design value day and additional emission controls, can be brought below the level of the NAAQS, it is likely that the area will comply with the standard. Of course, as with any nationwide analysis, there are many parameters that cannot be estimated on a city-specific basis. This could introduce significant error in projecting the compliance status of any individual area. However, the total number of non-attainment areas can be estimated with much more confidnce.

Table 2-2 illustrates the temporal distribution of the design value days for the 61 non-California urban non-attainment areas. Fifty-one of the 61 days, or 84 percent, occurred in the three-month summer period of June through August, and all but 6 of the design values (90 percent of the total) were recorded in the June-through-September period. It is worth noting that the four design values recorded in April all occurred on April 27th or later. In fact, three of the four April design value days occurred on April 28 or 29, 1983. These four values are all associated with abnormally warm spring days (maximum temperatures of 80° F or higher), and all are for areas in the northeastern part of the country. (A complete listing of the design value dates and the temperatures recorded on those dates is presented in Chapter 3.)

A second, broader analysis is available which examines the seasonal occurrence of all ozone violations for 47 non-California urban areas.[3] Only 47 areas (rather than 61) were examined because at the time of the analysis, areas were designated non-attainment on the basis of 1981-83 (rather than 1982-84) design values. The data for the analysis were taken from the SAROAD (Storage and Retrieval of Atmospheric Data) system, and included ozone data recorded at all monitoring sites within each of the urban areas. Reports of daily maximum one-hour ozone concentrations at each monitoring site, recorded for each day of the year, were obtained for 1980 and 1983: 1980 representing a recent year with a relatively high number of ozone violations, and 1983 representing the most recent complete data set at the time of that analysis. These years are still appropriate here, 1980 for the reason cited above and 1983 because it is the base year on which the environmental impact analysis (see Chapter 3) is based. Also, all of the current 61 non-attainment areas with design values well above the ozone NAAQS are included in the 47-area set. Those areas present only in the 47-area set or the 61-area set are areas with ambient ozone concentrations very close to the NAAQS. Thus, the conclusions drawn regarding the seasonality of the ozone noncompliance problem from this analysis remain valid.

Table 2-3 presents the results of the seasonal analysis for both 1980 and 1983. The data summarized in the upper portion of the table describe the distribution of total annual violations by month and by various combinations of summer months. "Total annual violations" are defined as the total number of days in which a one-hour average ozone concentration exceeding 0.125 ppm at any given site was recorded; since violations in a specific urban area are summed over all monitoring sites within that area, the total monthly violations for any specific non-attainment area can be more than 31.

Table 2-2

Distribution of Ozone Design Value Days

Month	Number of Ozone Design Value Days	Percent of Total
January	0	0
February	0	0
March	0	0
April*	4	7
May	0	0
June	16	26
July	15	25
August	20	33
September	4	7
October	1	2
November	0	0
December	1	2
Total	61	100

---

* The four design values recorded in April all occurred in the last 4 days of the month.

Table 2-3

Seasonal Trends in Ozone Violations

Months	Percent of Total Annual Violations: All 47 Areas 1980	All 47 Areas 1983	All 47 Areas Except Houston* 1980	All 47 Areas Except Houston* 1983
April	1	1	1	1
May	5	5	3	1
June	13	22	14	23
July	39	26	43	28
August	27	31	28	34
September	10	13	9	13
October	2	1	1	0
July & August	66	57	71	62
June - August	79	79	85	85
June - September	89	92	94	98
May - September	94	97	97	99

Average of Area-Specific Monthly Peaks (ppm)

Months	All O_3 Levels 1980	All O_3 Levels 1983
January	.055	.050
February	.075	.073
March	.082	.080
April	.101	.099
May	.123	.103
June	.151	.144
July	.162	.149
August	.151	.156
September	.134	.133
October	.101	.102
November	.084	.061
December	.067	.053

---

* Houston is excluded because of its anomalously large number of non-summer violations.

As indicated in the top half of Table 2-3, ozone violations are heavily concentrated in the warmer months, when temperatures and sunlight duration are most conducive to ozone formation. On the basis of the 1983 data, 80 percent of the non-attainment areas (38 of 47) experienced all ozone violations during a five-month period (i.e., May through September inclusive). Further, nearly all of the remaining areas recorded at least 80 percent of their violations during these 5 months. The major exceptions to the latter statement experienced very few ozone violations in 1983 (Scranton, PA had three violations, one in April; Miami had only one violation, also in April).

In both 1980 and 1983, Houston experienced a relatively large number of ozone violations, recording 193 and 217 annual exceedances (respectively) over its 13 monitoring sites. In 1980, 25 percent of these violations occurred outside of the May-September period; the 1983 figure is slightly lower at 18 percent non-summer violations. The fact that Houston recorded ozone concentrations at or above the NAAQS in every month of both years, while no other area recorded such levels in more than 8 different months in either year, further illustrates the unique nature of the ozone problem in that area.

In evaluating various seasonal options for in-use fuel volatility control, the most important factor is consideration of the period of time during which ozone reductions are needed most. The percentage distribution shown in the upper part of Table 2-3 is based on total violations at all monitors; thus, areas with more monitoring sites contribute more heavily to the distribution. Since Houston recorded a relatively high number of non-summer violations and also has more monitoring sites than most of the areas, the results are presented both with and without the Houston data.

As shown in Table 2-3, the month during which the highest percentage of all 1980 violations occurred was July, with 39 percent of the total; in 1983, August was the highest with 31 percent of total annual violations. In addition to individual months, the two-, three-, four-, and five-month periods recording the highest percentages of total violations are presented. The top portion of the table shows that in-use fuel volatility control between May and September (inclusive) would potentially impact 94 to 97 percent of ozone violations. If Houston is excluded, this five-month period encompasses virtually all ozone episodes. Four-month control (June-September) would have an impact on just slightly less of the ozone season -- 80 to 92 percent of total violations in all areas and 94 to 98 percent if the Houston data are excluded.

The lower section of Table 2-3 summarizes seasonal trends in peak ozone concentrations, showing the average of all areas' maximum ozone levels by month. As shown, average peak ozone concentrations show a definite trend, from highs of 0.156 to 0.162 ppm in July or August to lows of 0.050 to 0.055 ppm in January. Further, the average of the peak ozone concentrations exceeds the level of the NAAQS in May through September in 1980, and in June through September in 1983. Taken together with the information shown in the upper portion of the table, the seasonal nature of ozone NAAQS violations is clear.

The discussion above shows that, for those ozone control strategies that can be seasonally focused (such as volatility control), there are two primary choices for the period of control: June through September and May through September. The occurrence of four of the current 61 design value days in late April, and the greater potential to impact ozone violations, leads to the selection of May through September (inclusive) as the seasonal control period.

II. Effect of Volatility on HC Emission Factors

A. Gasoline Fueled Vehicle

1. Evaporative Emissions

Evaporative HC emissions from motor vehicles can be separated into the two basic categories of "diurnal" and "hot-soak" losses which result from different processes. Diurnal emissions consist of HCs both evaporated and displaced from the vehicle's fuel tank as the vehicle tracks the diurnal swing in ambient temperatures. Each day, as the fuel in the tank and the vapor above the fuel heat up, more of the liquid fuel evaporates and the vapor itself expands, with both phenomena causing HCs to be released into the atmosphere (unless captured by a control system). Fuel volatility, size of vapor space, initial ambient temperature, magnitude of the diurnal temperature swing, and driving patterns all impact the level of evaporative emissions from a vehicle's fuel tank.

Hot-soak emissions occur during the period immediately following engine shut-down (i.e., at the end of each vehicle trip). These losses will occur both as distillation from the fuel metering system (either a carburetor or a fuel injector) and as evaporation from the fuel tank. Evaporative emissions from the fuel metering system occur as part of a different process than that described for diurnal losses. When the engine is shut off, so is the cooling system. The engine block and surrounding area heat the engine coolant (which is no longer circulating) and other engine components, usually kept cool by the circulating coolant, before natural cooling begins to take effect. Any fuel remaining in the carburetor bowl, or leaking from a malfunctioning fuel injector, will undergo a distillation process during this time and vapors will be released to the atmosphere unless captured by a control device. Since the majority of hot-soak emissions arise from distillation, the volatility characteristics of the fuel and engine temperature have the greatest impact on the level of hot-soak emissions.

The fuel metering system was previously considered the only source of hot-soak emissions, but there have been recent indications that the fuel tank in fuel-injected vehicles can undergo a temperature change during vehicle operation as a result of recirculation of fuel heated by the engine. Vapor production in the tank would be the same type as that described above for diurnal losses. Because these tank losses are not in response to ambient temperature changes, they are classified as hot-soak emissions.

a. Factors Affecting Evaporative Emissions

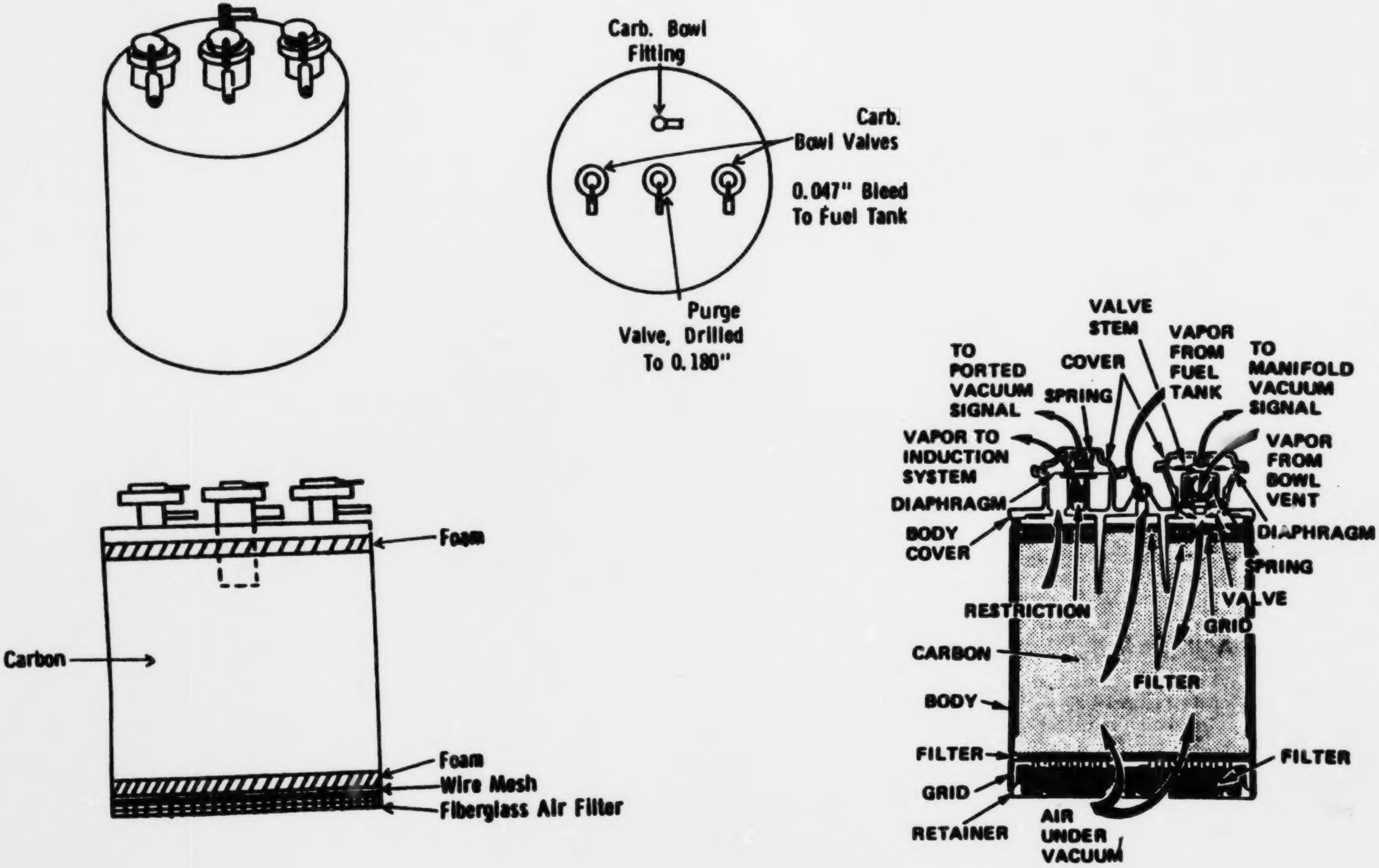
i. Evaporative Control System

Present evaporative emission control systems are composed of: 1) an activated carbon canister which adsorbs hydrocarbon vapor emitted from the vehicle fuel tank and carburetor bowl, and 2) the associated plumbing and hardware which control the loading and purging of the canister. Additionally, some carbureted systems use an air cleaner with an integrated charcoal element to further adsorb carburetor bowl and intake manifold vapors. When the engine is running, the stored vapor is desorbed, or purged, by drawing air through the canister to the engine intake system. The purge rate is controlled by the source of the vacuum (air cleaner, carburetor (above throttle blade) or intake manifold), the pressure drop through the canister and the size of the controlling orifice (located in either the canister or purge port). A diagram of a typical evaporative control system is presented in Figure 2-1.

The actual mass of gasoline vapors that an evaporative control system will continually adsorb and desorb during operation is referred to as the "system working capacity". This working capacity will be dependent upon many factors, some of which are internal to the system and others that are external. Among the internal factors are the volume of charcoal in the canister, the physical characteristics of the charcoal, the canister configuration, and the volume of purge air drawn through by the control system. Factors that also play a role in determining system working capacity, but which are currently subject to little or no control, include the temperature and humidity of purge air, and the vapor

Figure 2-1

Typical Evaporative Control System Canister


Carb. Bowl Fitting
Carb. Bowl Valves
0.047" Bleed To Fuel Tank
Purge Valve, Drilled To 0.180"
Foam
Carbon
Foam
Wire Mesh
Fiberglass Air Filter
VALVE STEM
TO PORTED VACUUM SIGNAL
COVER
VAPOR FROM FUEL TANK
TO MANIFOLD VACUUM SIGNAL
SPRING
VAPOR TO INDUCTION SYSTEM
VAPOR FROM BOWL VENT
DIAPHRAGM
BODY COVER
DIAPHRAGM
SPRING
VALVE
RESTRICTION
GRID
CARBON
FILTER
BODY
FILTER
FILTER
GRID
RETAINER
AIR UNDER VACUUM

concentration of the evaporative emissions. The temperature of the purge air could be controlled but it is not very practical. The vapor concentration effect was noted in an EPA report comparing the ability of two different charcoals to adsorb and desorb HC vapors using fuels of varying volatility, and will be discussed further in Chapter 4.[6]

Manufacturers can design evaporative emission control systems to have a specific system working capacity by adjusting those factors that are subject to their control, with consideration given to the variations in the external factors mentioned previously. Current certification tests are performed using Indolene, which has an average Reid Vapor Pressure (RVP) of 9.0 psi. Therefore, this is the volatility level at which current evaporative control systems are designed to meet the current evaporative HC standard of 2 grams/test. Actual in-use fuel, however, has an RVP closer to 11.5 psi during the summer months, which results in higher levels of evaporative emissions than those encountered by the canister during the certification test. Thus, there exists a significant difference in the levels of emissions current evaporative control systems are designed to capture and emissions encountered in actual operation.

ii. Fuel Volatility

Proper Measure of Fuel Volatility

A number of different gasoline properties may be used to indicate gasoline volatility. Each year, in a document referred to as D-439, the American Society for Testing and Materials (ASTM) publishes recommended limits for several gasoline volatility parameters, including Reid Vapor Pressure (RVP), distillation characteristics (such as the temperature at which a given percentage of gasoline is evaporated), and the temperature corresponding to a given gasoline vapor-to-liquid ratio (V/L). For every month of the year, each state is assigned a "volatility class" that represents ASTM's recommended limits on the volatility of gasoline sold in that state. The five gasoline volatility classes are designated as A, B, C, D, and E with a corresponding volatility limits as shown in Table 2-4. As indicated, Class A is the least volatile and Class E is the most volatile. It should be noted that these ASTM specifications are merely recommended levels and are not legally binding for gasoline refiners. A number of states have adopted ASTM standards as legal limits. However, the effectiveness of these limits depends directly on enforcement and it is questionable how strictly these limits are enforced in many states (California being an exception).

Table 2-4

ASTM D-439 Gasoline Volatility Specifications

ASTM Volatility Class	Max. RVP (psi)	Distillation Temp. (°F) at Given Percent Evaporated: Max. @ 10% (T_{10})	Min. @ 50% (T_{50})	Max. @ 50% (T_{50})	Min. Temp. @ V/L = 20 ($T_{20V/L}$, °F)
A	9.0	158	170	250	140
B	10.0	149	170	245	133
C	11.5	140	170	240	124
D	13.5	131	170	235	116
E	15.0	122	170	230	105

The major reason behind ASTM's assignment of volatility limits is the prevention of vapor lock at high ambient temperatures and problems of starting the engine under colder conditions. As shown in Table 2-4, values for RVP, vapor-liquid ratio, and distillation temperatures are defined for each of the five fuel volatility classes (A through E). In turn, minimum and maximum ambient temperatures under which no problems with cold startability or vapor lock would occur were calculated for each volatility class. Then, temperature data for each geographical area are used to select the appropriate volatility classes for each month of the year. A U.S. map indicating ASTM's state volatility class recommendations for the month of July is provided in Figure 2-2.

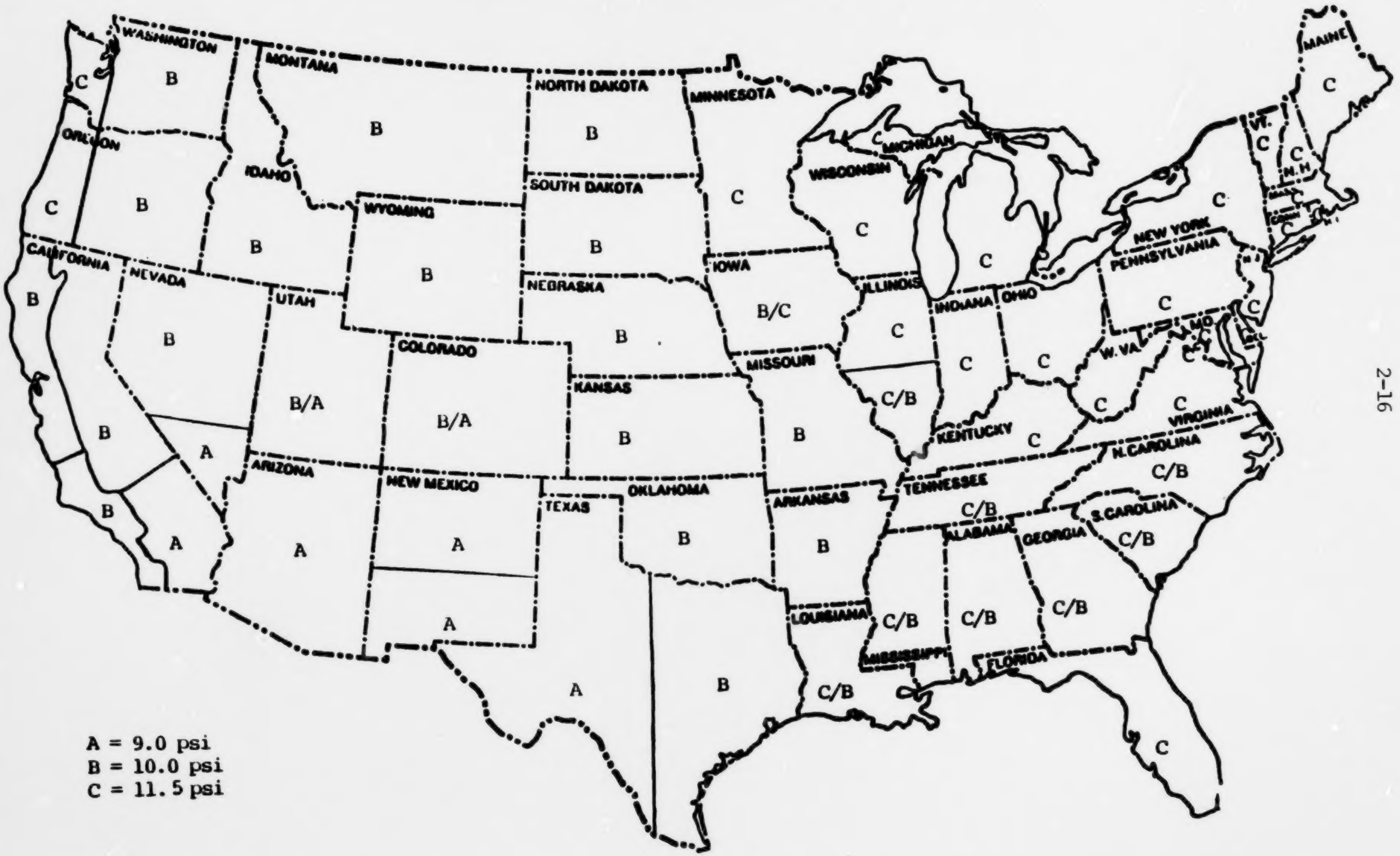
In order to determine the most significant gasoline volatility parameters with respect to the magnitude of evaporative HC losses, it is important to consider the source of the evaporative emissions. The measure of fuel volatility relevant to diurnal emissions should ideally reflect volatility at temperatures typically associated with a vehicle's fuel tank. The most widely accepted measure of volatility in relation to diurnal emissions is RVP, a measure of the fuel's vapor pressure at 100°F.[7,8]

Hot-soak emissions originate both from the fuel tank and the fuel metering system, as indicated previously. The process occurring in the fuel tank is much the same as with diurnal emissions. Therefore, RVP is an appropriate measure of volatility for this portion of the hot-soak emissions. On the other hand, since the temperatures experienced in the fuel metering system can be much higher than 100°F, RVP may not be ideal as an overall indicator of hot-soak emission levels. The relationship between temperature, volatility and evaporative losses is not as clear in a carburetor or fuel injector as in the fuel tank due to the complex interactions that occur.[9] Only limited work in this area has been done with fuel-injected vehicles, but carbureted vehicles have been studied fairly extensively.

Hot-soak losses from a carbureted vehicle are generally felt to be related also to the mid-range volatility of the fuel, given as the percent of fuel volume distilled in an ASTM D216 distillation at the peak temperature in the carburetor bowl.[7,9-12] This peak temperature will vary from vehicle to vehicle and may also be affected somewhat by the ambient temperature. An average value for the peak bowl temperature is around 160°F and, therefore, the percent of fuel evaporated at 160°F ($\%_{160}$), in addition to RVP, may be a relevant fuel parameter for estimating hot-soak losses.[7,10] EPA has performed emission tests on vehicles with fuels of equal RVP and varying $\%_{160}$ values. The results of this program are presented later in this section.

Figure 2-2

ASTM's July Volatility Classes


WASHINGTON
B
C
OREGON
B
C
MONTANA
B
IDAHO
B
NORTH DAKOTA
B
SOUTH DAKOTA
B
MINNESOTA
C
WYOMING
B
CALIFORNIA
B
B
B
NEVADA
B
A
A
UTAH
B/A
COLORADO
B/A
NEBRASKA
B
KANSAS
B
IOWA
B/C
MISSOURI
B
WISCONSIN
C
MICHIGAN
C
C
ILLINOIS
C
C/B
INDIANA
C
OHIO
C
KENTUCKY
C
ARIZONA
A
NEW MEXICO
A
A
TEXAS
A
B
OKLAHOMA
B
ARKANSAS
B
LOUISIANA
C/B
MISSISSIPPI
C/B
TENNESSEE
C/B
ALABAMA
C/B
GEORGIA
C/B
FLORIDA
C
S.CAROLINA
C/B
N.CAROLINA
C/B
VIRGINIA
C
W. VA
C
MD
C
DEL
PENNSYLVANIA
C
NEW YORK
C
N.J
C
VT.
C
N.H
C
MAINE
C
CONN
C
C

A = 9.0 psi
B = 10.0 psi
C = 11.5 psi

Theoretically, because total evaporative HC emissions are represented by the sum of hot-soak and diurnal losses, the ideal measure of fuel volatility to be used in evaluating various evaporative emission control strategies would most likely be some combination of both RVP and $\%_{160}$. The weighting given each of these factors would be expected to vary with vehicle type, as fuel-injected vehicles have significantly lower hot-soak emissions and, thus, their relative losses would be more dependent upon RVP. Also, operating temperatures can vary from model to model, so 160°F may not be the appropriate point on the distillation curve for all vehicles.

Some attempts have been made to incorporate both RVP and various distillation points into a volatility index. In an effort to correlate evaporative emissions to the volatility of gasolines and methanol/gasoline blends, DuPont developed the Evaporative Index (EI), as shown below:

$$EI = 0.85(RVP) + 0.14(\%_{200}) - 0.32(\%_{100}).[13]$$

In their application for a waiver of methanol blends, DuPont showed a correlation of EI versus evaporative emissions with an R^2 value of 0.86.[13] However, some criticisms have been raised with respect to the DuPont analysis, such as their combining the results of two independent testing programs without normalizing the results and the lack of higher volatility gasolines and blends in the analysis.[14,15]

The Front End Volatility Index (FEVI), which was developed for purposes other than emissions estimation (primarily the control of vapor lock), is defined as:

$$FEVI = RVP + 0.13(\%_{158}).[16]$$

This index essentially includes the two terms most relevant to evaporative emissions ($\%_{158}$ is very close to $\%_{160}$). However, it is currently unknown if the relative weighting of the two parameters is appropriate.

Another gasoline property used to measure volatility is the temperature corresponding to a specified gasoline vapor-to-liquid ratio (V/L) at atmospheric pressure. This V/L is the volume of vapor formed at atmospheric pressure and test temperature divided by the initial volume of liquid gasoline tested. The temperature at which this vapor-to-liquid ratio is equal to 20 at atmospheric pressure is designated $T_{20V/L}$. The $T_{20V/L}$ parameter is included in the ASTM volatility specifications (shown in Table 2-4) and, according to API, is commonly used for blending purposes by refiners. Since limiting $T_{20V/L}$ can affect the other evaporative-related fuel parameters, it deserves further discussion here.

ASTM D-439 provides an empirical equation defining $T_{20V/L}$ as a function of the following parameters: RVP, the temperature at which ten percent of the gasoline is evaporated (T_{10}), and the temperature at which 50 percent of the gasoline is evaporated (T_{50}). This equation is:

$$T_{20V/L} = 114.6 - 4.1(RVP) + 0.2(T_{10}) + 0.17(T_{50}).[17]$$

In the above equation for $T_{20V/L}$, RVP contributes significantly more to $T_{20V/L}$ than does T_{10} or T_{50}. According to survey data, fuels with RVPs ranging from 11.5 to 9.5 psi have T_{10}s ranging from 108-120°F and T_{50}s ranging from 210-220°F.[18] This 2-psi RVP range accounts for roughly an 8°F change in $T_{20V/L}$, if T_{10} and T_{50} are held constant. If the corresponding T_{10}s and T_{50}s for the different RVPs are used in the $T_{20V/L}$ equation, then the $T_{20V/L}$ changes by nearly 12°F. This indicates that RVP is the major factor affecting $T_{20V/L}$, but T_{10} and T_{50} are not negligible.

From the above discussion, it appears that RVP and $\%_{160}$ are the most relevant of the available fuel parameters to indicate evaporative emission potential. As previously mentioned, RVP, a measure of volatility at 100°F, is relevant because the maximum fuel tank temperature during a diurnal is less than 100°F. The $\%_{160}$ is relevant for hot-soak emissions since the maximum temperature in the carburetor during a hot-soak is around 160°F. The other parameters, EI, FEVI and $T_{20V/L}$ all essentially combine RVP with higher-temperature volatility indicators, but it is not clear that any of the three particular combinations adequately represent the overall evaporative emission potential for motor vehicles. It appears safer to address the RVP and $\%_{160}$ parameters separately at this point. However, only limited data is available on the effect of $\%_{160}$ on evaporative emissions. This analysis will focus primarily on RVP as the most relevant measure of fuel volatility with an independent analysis of the $\%_{160}$ effect on hot-soak emissions.

Historical and Future Trends in Gasoline Volatility

Over the past decade, the volatility of commercial gasoline has gradually, but steadily, been increasing. Trends in commercial gasoline volatility were traced using results of two separate fuel surveys prepared each summer by the National Institute for Petroleum and Energy Research (NIPER) and the Motor Vehicle Manufacturers Association (MVMA). Summer gasoline volatility is the focus because, as concluded in Section I of this chapter, in-use fuel control from May through September could have an impact on the majority of ozone violations. Table 2-5 presents RVP trends for the 15

Table 2-5

NIPER Survey Results[19]: Summer Gasoline RVP Trends by Region*

Region	Years												% Increase over 1974
	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	
Northeast	9.8	10.0	10.2	10.7	10.5	10.5	10.8	10.8	10.9	10.5	10.7	11.2	14
Mid-Atlantic Coast	9.3	10.1	10.1	10.4	10.1	10.2	10.3	10.6	10.8	10.7	10.8	11.1	19
Southeast	9.6	9.6	9.7	9.5	9.4	9.6	9.8	9.9	10.1	10.3	10.2	10.6	10
Appalachian	10.5	10.6	10.5	10.4	10.1	10.6	10.5	10.9	11.1	11.4	11.1	11.5	10
Michigan	10.5	10.4	10.6	11.0	11.2	10.9	11.3	10.9	11.2	11.6	11.5	11.8	12
Northern Illinois	9.5	10.5	10.3	11.0	10.8	10.9	10.9	11.1	10.8	11.7	11.3	11.2	18
Central Mississippi	10.1	10.1	9.9	9.9	10.1	10.4	10.3	9.7	10.5	11.0	10.9	11.1	10
Lower Mississippi	9.4	9.6	9.6	9.5	9.8	9.5	9.7	9.3	10.1	10.1	10.0	10.5	12
Northern Plains	--	9.6	9.9	--	--	9.2	9.8	--	11.0	11.0	10.5	11.3	18
Central Plains	--	9.1	9.2	9.0	8.8	9.2	9.2	--	10.2	10.0	10.0	10.3	13
Southern Plains	9.2	9.3	9.2	9.3	9.1	9.5	9.2	9.7	10.0	9.8	9.8	10.1	10
Southern Texas	9.1	9.5	9.4	9.6	9.5	9.4	9.2	9.4	10.3	10.2	10.3	10.1	11
Southern Mountain	8.4	8.9	8.7	8.8	8.9	8.7	8.9	8.4	8.8	9.1	8.9	9.4	12
Northern Mountain	8.9	10.1	9.5	9.9	9.9	9.6	9.5	9.2	10.4	10.4	9.7	10.4	17
Pacific Northwest	9.5	9.9	10.6	10.4	10.0	10.3	10.8	11.0	10.8	11.2	10.8	11.4	20
National Average** (excluding California)	9.5	9.8	9.8	10.0	9.9	9.2	10.0	10.1	10.5	10.6	10.4	10.8	14

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* Unleaded regular gasoline only (R + M/2 less than 90).

** Calculated as a straight arithmetic average of the 15 regional averages listed.

non-California regions included in the NIPER survey. As shown, overall non-California averages indicate a 14-percent increase in summer unleaded fuel RVP levels over the past 11 years. Increases within individual regions vary between 10 and 20 percent, with the greatest summer increase occurring in the Pacific Northwest.

To examine volatility trends over the past twenty years, it is necessary to look at leaded fuel which, of course, has been in use longer than unleaded fuel. National-average results of NIPER leaded gasoline surveys are presented graphically in Figure 2-3.[19] As shown in the top graph, the most significant summer RVP "boosts" occurred first in the 1972-74 period, and then again in 1981. Prior to 1972, summer fuel RVP levels were well within the range specified in the Code of Federal Regulations (CFR) for certification test fuels (8.7 to 9.2 psi); however, by the time the SHED* test began with the 1978 model year, the certification fuel RVP had been exceeded by the national average RVP of in-use fuel (approximately 9.6 psi). Since then, the CFR specifications have become even less representative of commercial fuel volatility, based on a 1985 summer leaded fuel average RVP of 10.5 psi for the nation. Curves for T_{90}, T_{50}, and T_{10}, also presented in Figure 2-3 support the trend in increasing gasoline volatility, as well.

Results of the other fuel survey mentioned -- conducted by MVMA -- are presented in Table 2-6.[18] Here, instead of segregating by geographic region, average volatility characteristics for unleaded regular gasoline (alcohol free) are shown for ASTM Classes A, B, and C (as defined in Table 2-4). According to these survey results, the average RVP in Class C areas has increased by almost ten percent over the past nine years to a level slightly above 11.0 psi. Trends in other volatility parameters such as T_{10}, T_{50}, $\%_{158}$, and $T_{20V/L}$ (all defined in the previous section) are also shown in Table 2-6. These trends also indicate increasing fuel volatility over the past few years (i.e., lower T_{10}, T_{50}, and $T_{20V/L}$, and higher $\%_{158}$). It is important to note that $\%_{158}$ -- close to the $\%_{160}$ parameter associated with hot-soak emissions in the previous section -- has increased significantly by 28 percent (from 25.5 percent to a current average level of 32.6 percent) in Class C areas.

Pool average gasoline volatility properties for Class C gasolines are similar to those of unleaded regular gasoline described above. From 1977 to 1986, pool average RVP and

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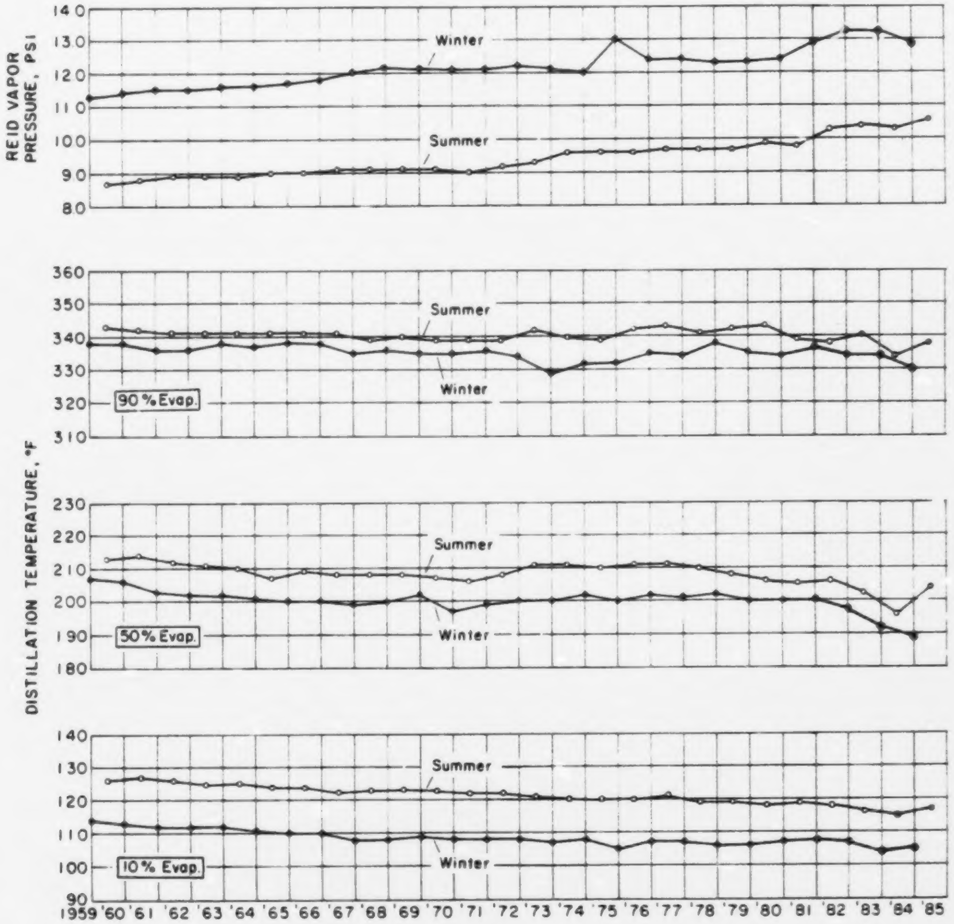
* Sealed Housing Evaporative Determination, which is the current test procedure.

Figure 2-3

Volatility Trends In Leaded Gasoline

(NIPER Survey Results) [19]



Trends of certain characteristics of leaded (regular) grade gasoline through summer 1980; leaded antiknock index (R+M)/2 below 93.0 grade gasoline beginning winter 1980-81.

Table 2-6

MVMA Survey Results[18]:
Summer Gasoline Trends by ASTM Volatility Class*

Year	Volatility Class	No. of Gasolines Sampled	Avg. RVP (psi)	% of Sample Above ASTM RVP Max.	Avg. T_{10} (°F)	Avg. T_{50} (°F)	Avg. $\%_{158}$ (%)	Avg. $T_{20V/L}$ (°F)	% of Sample Below ASTM Minimum $T_{20V/L}$
1977	A	37	8.53	27.0	131.6	225.9	21.5	144.3	24.3
	B	66	8.72	0.0	128.0	218.3	23.4	141.6	4.6
	C	121	9.94	0.0	121.9	220.9	25.5	135.8	0.0
1978	A	38	8.25	13.2	129.0	222.9	22.5	144.5	23.7
	B	68	8.56	0.0	127.8	219.8	23.2	142.4	4.4
	C	123	9.67	0.8	120.8	220.0	25.8	136.5	0.0
1979	A	37	9.79	64.9	124.4	223.7	24.0	137.4	62.2
	B	67	10.10	55.2	123.6	219.4	25.0	135.2	47.8
	C	120	11.33	37.5	115.2	221.4	28.0	128.8	22.5
1980	A	39	8.27	20.5	123.8	222.5	23.4	143.3	28.1
	B	66	8.71	0.0	120.9	217.9	25.6	140.1	4.6
	C	124	9.88	1.6	113.0	218.5	28.4	133.8	0.8
1981	A	41	8.65	22.0	122.4	219.1	25.8	140.9	26.8
	B	66	9.30	6.1	122.0	218.1	25.9	137.9	10.6
	C	126	10.46	1.6	114.6	215.6	29.3	131.3	4.0
1982	A	37	9.16	37.8	123.8	220.0	25.2	139.2	43.2
	B	65	9.79	33.8	122.5	218.4	26.0	136.1	30.8
	C	125	11.06	28.8	114.0	215.6	29.6	128.7	11.2
1983	A	39	9.06	33.3	122.4	220.2	25.4	139.4	46.2
	B	64	9.65	31.2	120.1	216.6	26.5	135.9	29.7
	C	128	10.84	15.6	113.2	214.7	29.6	129.3	10.9
1984	A	39	8.80	28.2	118.7	210.9	28.5	138.1	51.3
	B	60	9.54	28.3	117.5	210.7	28.7	134.8	43.3
	C	125	10.89	22.4	108.8	206.7	32.7	126.8	30.4
1985	A	30	9.17	43.3	125.0	214.3	25.9	138.4	56.7
	B	59	9.89	45.8	121.4	212.7	27.2	134.5	42.4
	C	106	11.28	40.6	114.9	211.1	29.9	127.2	26.4
1986	A	32	9.80	68.8	115.1	203.4	30.3	132.0	81.2
	B	60	9.86	45.0	117.5	208.0	29.2	133.0	43.3
	C	106	11.06	30.2	108.9	202.4	32.6	125.4	40.6

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* Alcohol-free unleaded regular gasoline only (R + M/2 less than 90).

$\%_{158}$, as determined from MVMA survey data (unleaded regular, unleaded premium, and leaded regular gasolines weighted 65 percent, 18 percent, and 17 percent, respectively) have both increased significantly. RVP has increased from 9.94 to 11.05 psi, and $\%_{158}$ increased from 26.6 to 32.2 percent.

Alcohol blends, as a whole, have higher volatility than do alcohol-free gasolines. Laboratory experiments yield an increase in RVP of between 0.5 to 1.0 psi for splash-blended ethanol blends. Based on the MVMA summer surveys, the average RVP of in-use ethanol blends tends to be closer to 1.0 psi greater than the average RVP of in-use straight gasolines. The MVMA survey data reviewed above for alcohol-free gasoline volatility properties contained data on ethanol blends, but did not have volatility properties for methanol blends. Average RVP for eleven 1985 ASTM Class C unleaded regular gasoline samples containing an average of 9.1 percent ethanol was 12.5 psi. Average $\%_{158}$ of these blends was 44.0 percent. These levels are very similar to those of twenty 1983 and 1984 gasoline samples containing an average of 9.4 percent ethanol. Average RVP from these 1983 and 1984 ethanol blend samples was 12.3 psi, and average $\%_{158}$ was 43 percent. Over the three years, $\%_{158}$ ranged from 30 to 55 percent while RVP ranged from 10.9 to 13.4 psi. These data indicate that Class C ethanol blends are significantly more volatile than Class C alcohol-free gasolines.

According to some theories, the increase in fuel volatility seen in alcohol-free gasoline is linked to the lead phasedown in gasoline over the past decade. Because of the reduction and/or elimination of lead in gasoline, the traditional octane-booster, refiners must process heavier crudes in order to obtain the clear, high-octane fractions. As more crude undergoes hydro-cracking, more butane is produced. Since butane enhances octane, and because the supply is in excess, it is allowed to remain a component of the gasoline. Unfortunately, butane is also a major volatility enhancer and its abundance is most likely the major reason for the increase in RVP over time.

As mentioned earlier, ASTM's volatility specifications are not enforceable by law, but are merely levels agreed upon by members of the refining industry and automobile manufacturers. However, some states have adopted ASTM's RVP limits as part of their own gasoline inspection laws, which are enforceable.

Among the states which have adopted fuel volatility controls, the assigned RVP limits vary from month-to-month (as they do in the ASTM specifications) according to temperature conditions.* For the purposes of comparison to ASTM's D-439 limits, July was focused on, because of the high number of ozone violations which occur during this summer month (as mentioned in Section I of this chapter).

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* The only exception to this is Hawaii, which holds RVP constant throughout the year at 11.5 psi.

A comparison of non-California state laws versus ASTM limits on RVP for July is presented in Table 2-7. As shown, 22 of the states do not currently have laws governing the RVP of gasoline sold within their boundaries.* Another 22 states have simply adopted ASTM's current year-round D-439 limits as law; in addition to these, three more states have RVP limits that correspond to ASTM's specifications during July but not all of the rest of the year. Among those state laws that differ from ASTM's D-439, there is a month-to-month variation involved in the comparison; for example, Arizona is less restrictive than ASTM in March, April, and between August and November. Since July is the focus here, the comparison is simplified. During July, three states are less restrictive than ASTM. No states are more restrictive than ASTM during July.

In an effort to determine the effectiveness of ASTM's recommendations and State laws, fuel survey data were compared to these standards. Part of this comparison was shown previously in Table 2-6. As indicated there, over 30 percent of the Class C fuels sampled by MVMA in 1986 exceeded ASTM's maximum RVP specification of 11.5 psi; of these same samples, over 40 percent were below ASTM's recommended minimum level for $T_{20V/L}$.

In Table 2-8, this comparison is put on a state-by-state basis. Here, the states are divided between those that have implemented gasoline RVP standards and those that have not. In turn, 1982-84 NIPER summer survey results for these states were compared to both ASTM and State RVP standards in effect at that time for the month of July. As shown, 11 states had average RVPs above their respective ASTM specifications; ten of these states had their own RVP standards and the other one did not. Further, of the 28 states which had their own RVP limits (Hawaii excluded), roughly one-third of them had average summer RVPs above these State standards. Therefore, enforcement appears to be somewhat ineffective.

Several basic conclusions can be made from the information presented in the above discussions. One, gasoline volatility has been gradually increasing over the past two decades and no substantial data exist to indicate that this trend will not continue. Two, ASTM recommendations and State-implemented volatility limits appear to be somewhat ineffective in controlling gasoline volatility. Even if ASTM specifications

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* Washington, D.C. is included as one of the 22 states.

Table 2-7

Comparison of July RVP control: State Laws versus ASTM Limits*

States Same as ASTM	States Less Restrictive than ASTM**	States With No RVP Specifications
Arizona (A)**	Alabama (C/B)	Alaska (D)
Arkansas (B)	Indiana (C)	Connecticut (C)
Colorado (B/A)	Maryland (C)	Washington, D.C. (C)
Delaware (C)		Kansas (B)
Florida (C)		Kentucky (C)
Georgia (C/B)		Maine (C)
Hawaii (C)		Massachusetts (C)
Idaho (B)		Nebraska (B)
Illinois (C,C/B)		Nevada (A,B)
Iowa (B/C)		New Hampshire (C)
Louisiana (C/B)		New Jersey (C)
Michigan (C)**		New Mexico (A)
Minnesota (C)		New York (C)
Mississippi (C/B)**		Ohio (C)
Missouri (B)		Oklahoma (C)
Montana (B)		Oregon (B,C)
North Carolina (C/B)		Pennsylvania (C)
North Dakota (B)		Tennessee (C/B)
Rhode Island (C)		Texas (A,B)
South Carolina (C/B)		Vermont (C)
South Dakota (B)		Washington (B,C)
Utah (B/A)		West Virginia (C)
Virginia (C)		
Wisconsin (C)		
Wyoming (B)		

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* July ASTM volatility class specifications for each state given in parentheses, excluding California.

** States whose year-round volatility controls differ from ASTM specified levels.

Sources:

- ASTM's Standard Specification for Automotive Gasoline, D-439-83.
- "Summary of State Regulation of Reid Vapor Pressure in the Forty-Nine Non-California States" prepared for EPA by ESI International, Inc., July 25, 1986.

Table 2-8

Comparison of 1982-84 NIPER Survey Results [19] to July ASTM and State RVP Standards

	States with RVP Standards					States without RVP Standards				
	A*	A/B	B	B/C	C	A*	A/B	B	B/C	C
Max. ASTM RVP (psi)	9.0	10.0	10.0	11.5	11.5	9.0	10.0	10.0	11.5	11.5
Avg. of State RVP Standards (psi)	9.0	9.8	10.1	10.5	11.7	--	--	--	--	--
No. of States**	2	2	8	8	8	0	2	2	2	14
No. of States with Average RVPs above ASTM Specs.	2	0	7	0	1	--	0	0	0	1
No. of States with Average RVPs above State Stds.	2	0	5	1	1	--	--	--	--	--

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* "A" through "C" designate ASTM volatility classes as defined in ASTM's D-439 and reviewed in Table 2-4.

** Hawaii and Alaska excluded due to lack of fuel survey data.

were currently restricting RVP, which they may indeed be doing for some gasoline refiners, there is some speculation that ASTM specifications could be changed in the future. Revisions have been made in the past as vehicles have been designed to handle more volatile fuels. The projected widespread use of fuel injection systems continues this trend, so a relaxation of the current ASTM RVP limits is not inconceivable. Third, the current average RVP in Class C areas is roughly 11.0 psi, which is approaching the maximum ASTM specification of 11.5 psi. Based on these observations, then, this study assumes that, by 1988, gasoline RVP will on average rise to equal the ASTM limits for each state.

iii. Alcohol Blends

As a result of the oil crisis in the early 1970's, efforts were begun in the United States to reduce the dependence on imported oil. One idea introduced was the use of alcohols in gasoline to extend the supply of gasoline. The Environmental Protection Agency (EPA), under Section 211(f) of the Clean Air Act, must approve any new unleaded fuels which are not substantially similar to fuels already permitted in the market. There is currently one ethanol/gasoline blend and two methanol (and cosolvent)/gasoline blends allowed by waivers. A list is shown in Table 2-9. Currently in the United States, ethanol blends comprise around 7 percent of the total gasoline market whereas no methanol blends are currently being marketed primarily because of low oil prices.[20]

The addition of a polar alcohol affects the properties of the non-polar gasoline to which it is added. The primary effect is on the distillation curve and, thus, the parameters associated with volatility. Two of these parameters, as discussed earlier for gasoline are RVP, and $\%_{160}$.

Although the exact distillation effects of alcohol addition to gasoline vary for every base gasoline, some general effects are common. Theoretically, the addition of a pure compound to gasoline causes the percent evaporated at a specified temperature, compared to the straight gasoline, to decrease at temperatures below the boiling point of the compound added. At that point, that compound is distilled off and the percent evaporated at higher temperatures (compared to straight gasoline) is increased by the presence of the compound. However, both methanol and ethanol form azeotropes with many of the components in gasoline. An azeotrope is a mixture of a particular composition of two or more components which, in the case of alcohols and gasoline, has a constant boiling point lower than that of either individual compound. The combination of these two effects causes the percent of fuel evaporated at certain temperatures to be greater for an alcohol

Table 2-9

Current Clean Air Act Section 211(f) Waivers

Name	Date Granted	Limitations
1. Gas Plus Inc. "Gasohol"	12/16/78 (w/o decision)	-up to 10% (vol.) anhydrous EtOH -no volatility limits
2. ARCO "Oxinol"	11/7/81	-up to 4.75% (vol.) MeOH -up to 4.75 (vol.) TBA -ratio of MeOH: TBA cannot exceed 1 -ASTM gasoline volatility limits
3. DuPont (original) (reconsidered)	 1/14/85 10/22/86	-up to 5% (vol.) MeOH -at least 2.5% (vol.) cosolvent (EtOH, propanol, butanols) -corrosion inhibitor -ASTM gasoline volatility limits per reconsideration of original waiver.

EtOH = ethanol.
MeOH = methanol.
TBA = tertiary butyl alcohol.

blend than for straight gasoline, and to an extent much greater than the percentage of the alcohol alone. This effect on distillation occurs primarily in the boiling temperature range from the lowest-boiling azeotrope to the highest-boiling gasoline component forming an azeotrope.

The effect on the distillation curve is also dependent on the alcohol added. The increase in $\%_{160}$ for ethanol blends is between ten to 15 percent. The increase in $\%_{160}$ for methanol/cosolvent blends is five to ten percent. Typical distillation curves for ethanol blends and methanol blends are shown in Figures 2-4 and 2-5, respectively.

As discussed earlier, RVP is a measurement of the volatility of a fuel at 100°F. Since the vapor pressures of methanol and ethanol are lower than gasoline at 100°F, the addition of these alcohols to a gasoline could theoretically cause the RVP of the alcohol blend to be lower than that of the straight gasoline. Once again, however, the presence of highly volatile azeotropes offsets this effect and causes an increase in the RVP. The precise increase in RVP varies for every base gasoline, but the increases from each alcohol are generally similar. For the addition of methanol with a cosolvent (ethanol, propanols, and/or butanols) to gasoline at five-ten percent of total volume, the increase in RVP two to 2.5 psi. The increase in RVP for the addition of two-ten percent (by volume) ethanol to gasoline is 0.5 - 1 psi.[14]

The effects of alcohol addition on RVP, and $\%_{160}$ can be counteracted by adjusting the contents of the gasoline to which the alcohol is added. By removing lighter hydrocarbons (such as butanes and/or pentanes), the RVP or $\%_{160}$ of the final blend can be controlled to levels of the original straight gasoline.

However, even with control of alcohol blend volatility, there can be an increase in in-use volatility due to intermittent use of blends and gasoline. A phenomenon called commingling can occur when an alcohol blend is added to a tank partially filled with straight HC gasoline, wherein the RVP of the mixture can be significantly higher than the RVP of the original gasoline or blend. Commingling is depicted in Figure 2-6, where the increase in RVP (over the straight HC gasoline level) is shown as a function of blend ratio and type of blend. For example, in the top plot, if a 1:1 MeOH/isopropyl alcohol blend (9.6 percent by volume) is added to fill a 60-percent full tank of straight HC gasoline, the RVP of the new mixture (i.e., full tank) will be roughly 1.0 psi higher than that of the original straight HC gasoline.

Figure 2-4

Typical Methanol Blend Distillation Curves [21]

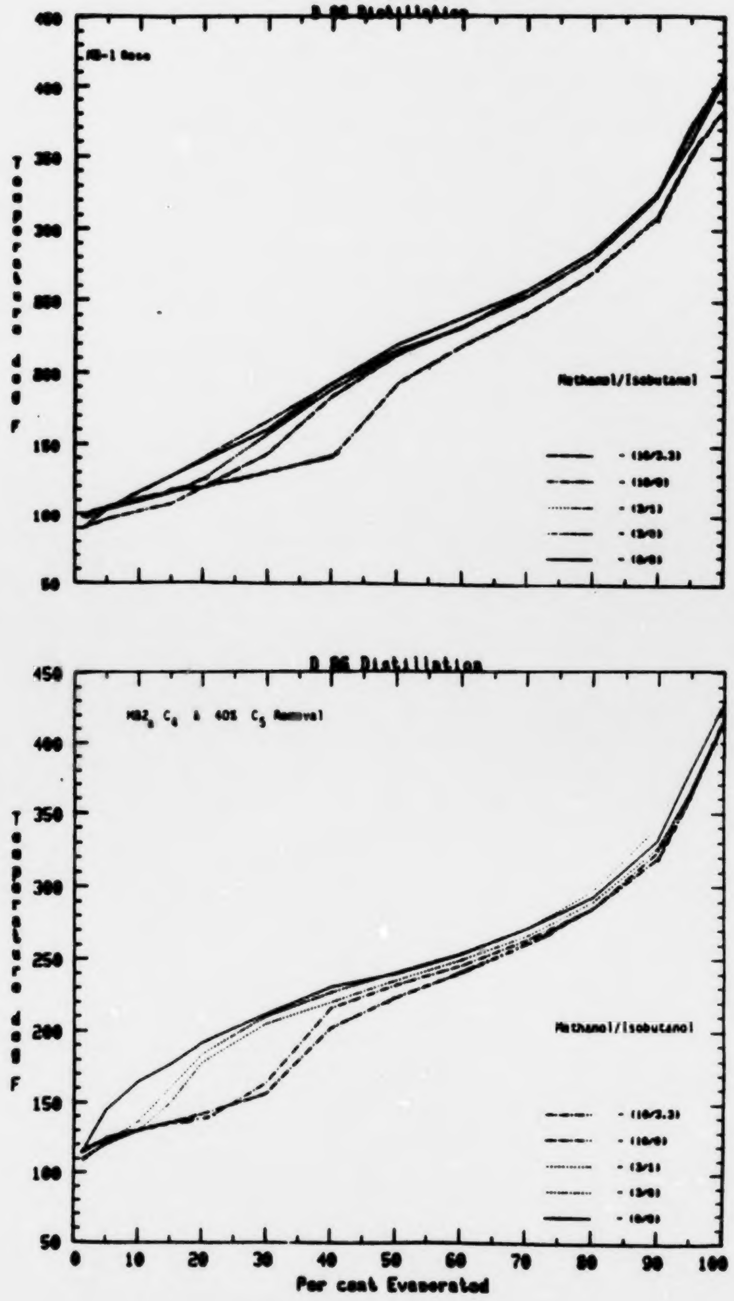


Figure 2-5

Typical Ethanol Blend Distillation Curves [22]

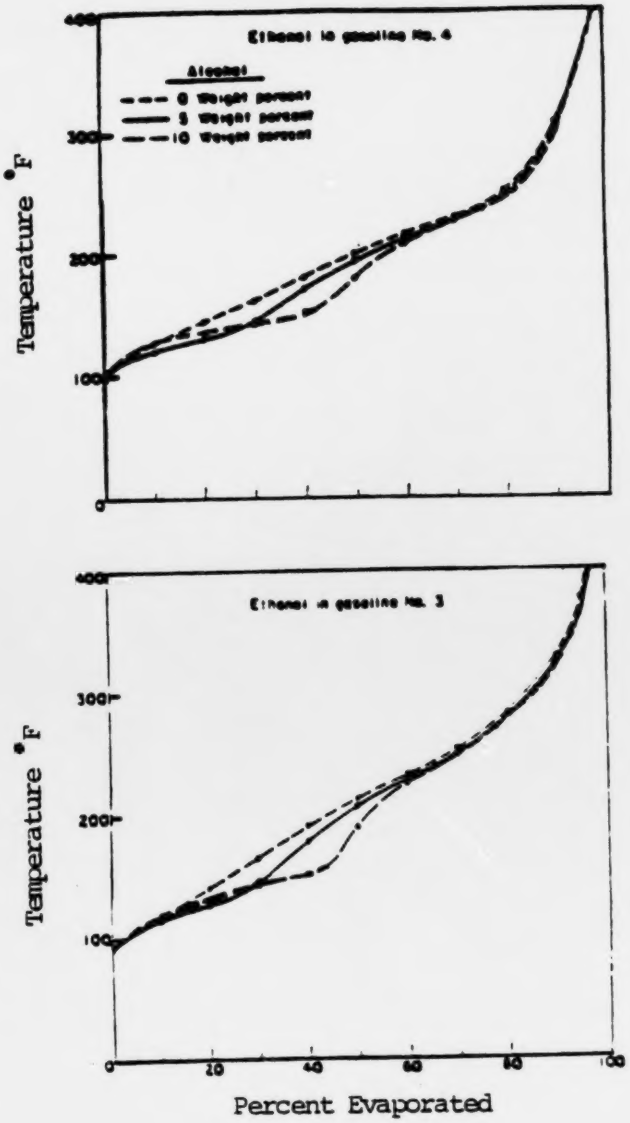
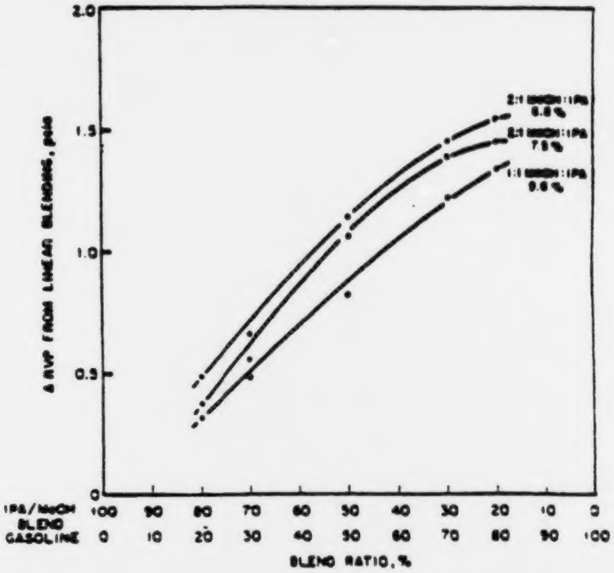
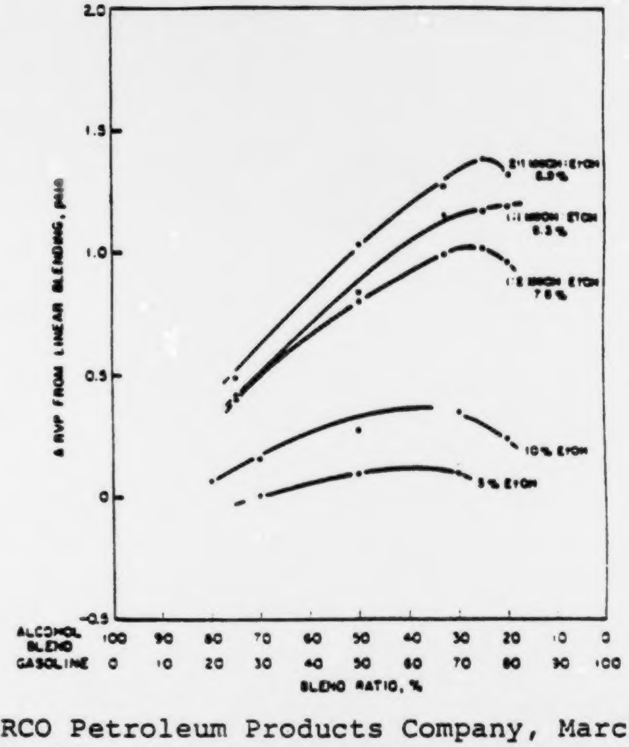


Figure 2-6

COMINGLING VAPOR PRESSURE EFFECTS MeOH/IPA BLENDS WITH ALL HYDROCARBON GASOLINE



COMINGLING VAPOR PRESSURE EFFECTS EtOH AND MeOH/EtOH BLENDS WITH ALL HYDROCARBON GASOLINE



Source: ARCO Petroleum Products Company, March 12, 1985 (in letter to Craig Harvey, EPA)

The increase in volatility due to commingling has been shown to be a function of the percentage of stations selling blends, the amount of fuel remaining in the fuel tank when refilling, and the habits of the buyer (i.e., whether fuel is bought at random or loyally).

iv. Ambient Temperature Conditions

In addition to RVP, daily ambient temperature conditions can also impact the level of evaporative emissions. Diurnal losses are dependent upon not only the ambient temperature excursion (daily maximum minus daily minimum), but also on the absolute magnitude of these temperatures. Hot-soak losses are also dependent on ambient temperature. For example, a vehicle undergoing a 30°F diurnal change at an average temperature of 90°F would be expected to have significantly greater diurnal and hot-soak losses than a vehicle experiencing only a 15°F diurnal difference at an average temperature of 75°F. FTP temperature specifications are 60° to 84°F for the diurnal test and 81°F for the hot-soak test. These temperature conditions are not completely representative of in-use summer temperature conditions. Based on daily July 1985 weather data from the National Oceanic and Atmospheric Administration, diurnal temperature swings tend to be less than 24°F but start at temperatures higher than 60°F. The temperature of the hot-soak will depend upon the time of the day at which it occurs.

In an effort to quantify the magnitude of such temperature (and RVP) differences, an EPA-sponsored test program was carried out to measure diurnal and hot-soak losses at various ambient temperature conditions. This test program conducted for EPA at the Automotive Testing Laboratories (ATL) included a matrix of three fuel RVPs, three diurnal starting temperatures, three diurnal temperature excursions, and three average hot-soak temperatures.[23] The standard EPA test procedure (i.e., diurnal temperatures between 60°F and 84°F, and average hot-soak temperature of roughly 82°F) was represented in the full test matrix.

Diurnal emissions data from this ATL program are analyzed later in this chapter. There, the diurnal averages are compared to theoretical emissions indexes calculated for each ATL test condition via the diurnal emissions model developed for this analysis. Hot-soak emission data will not be analyzed because of inconsistencies between hot-soak emission measurements at EPA and ATL.

v. Fuel Weathering

The volatilities reported in various fuel surveys (e.g., NIPER, MVMA) represent those levels measured at the gasoline pump. However, as the gasoline in the vehicle's fuel system responds to daily diurnal temperature changes and engine heat, some of the lighter hydrocarbons are lost. Thus, the volatility of the fuel gradually decreases. This phenomenon of "weathering" is an important consideration in assessing evaporative emissions that actually occur in the field. The analysis of weathering effects on in-use diurnal emissions is presented later in this chapter. The effects of weathering on hot-soak emissions will not be examined since neither ambient temperature effects nor temperature and RVP variability effects have been included in the in-use hot-soak model. It is expected that including these effects would tend to offset much of the predicted decrease in hot-soak emissions due to fuel weathering as occurs with the diurnal model.

vi. Driving Patterns

The way in which a vehicle is driven (i.e., the number of trips per day, the length of the trips, and the time at which the trip is taken) affects the amount of HC emissions from a motor vehicle. As is explained in the following sections, the effects of temperature, fuel volatility, fuel weathering, and in-use fill level have been taken into account in this analysis. However, the effects of the driving pattern distribution on emissions are not taken into account. The complicating factor is that an unlimited number of driving patterns exist. Driving patterns vary anywhere from vehicles which do not drive for several days in a row, whose canister can become fully saturated, to vehicles which have many trips per day, and possibly experience an interrupted diurnal but many hot-soaks. Other vehicles regularly experience long trips during which the canister is completely purged, resulting in very low emissions.

The revised MOBILE3 model used for this analysis does vary the number of trips per day and number of miles travelled per day by vehicle age. The average fleet values are 3.05 hot-soaks per day, 1 diurnal per day, and 26 miles per day. (The trip length in the June 1984 MOBILE3 report was 31.1 miles per day.) However, due to the complexity of modeling in-use driving patterns and the lack of data from which to derive the effect of driving patterns on both exhaust and evaporative HC emissions, the effect of different driving patterns has not been included in this analysis.

Failing to include the effects of the driving pattern distribution on in-use evaporative emissions may not have as large an effect on the results of this study as might be expected. For example, in the long-term, when certification fuel RVP has been made equal to in-use fuel RVP (and thus the excess emissions, which occur when operating a vehicle on a fuel more volatile than it was certified on, are nearly eliminated), the incremental evaporative emission reductions due to lowering in-use fuel volatility from current levels, arise primarily from malmaintained/defective vehicles, tampered vehicles and the gasoline distribution system.

With respect to the first two emission sources, the evaporative control systems on these vehicles are inoperative and result in the release of uncontrolled evaporative emissions directly into the atmosphere. Canister purge is not likely a factor in determining these emissions, and it is canister purge that is most affected by the variety of driving patterns.

Thus, the total amount of hot-soak emissions from these vehicles would depend on the total number of trips taken (i.e., the total number of hot-soaks experienced), but the emissions per hot-soak would be independent of the number of trips per day and the amount of driving. Since MOBILE3 represents the average number of trips per vehicle very well, it should represent total hot-soak emissions from these vehicles quite well, despite the lack of driving pattern distribution data.

On the other hand, the total amount of diurnal emissions from these vehicles could be affected by driving patterns if a trip interrupts the daily diurnal. During a trip, however, the fuel in the gas tank heats up to temperatures above the ambient temperature. This results in "running losses" which, on a properly operating vehicle, are vented through the evaporative control system to the engine (or directly to the engine) and combusted. In malmaintained/defective vehicles and tampered vehicles, these running losses would essentially be vented to the atmosphere. The interruption of the diurnal by driving could actually increase emissions over that of an uninterrupted diurnal. Driving at other times during the day would actually create artificial diurnals which results in more emissions to the atmosphere; these running losses are not considered by our evaporative emissions model. Thus, our model may actually underestimate the incremental emission control associated with additional long-term in-use RVP control.

The absence of driving patterns still may have an effect on the emissions of properly operating vehicles. However, as will be seen in Chapter 6, the initial step of matching in-use and certification fuel RVP at 11.5 psi in Class C areas is so cost effective that a 50 percent decrease in the estimated evaporative emission reduction would still leave the step very cost effective (i.e., less than $100 per ton).

b. Results of In-Use Motor Vehicle Testing

This section presents test data from EPA's in-use motor vehicle emission factor (EF) program in an attempt to quantify the effect of the factors mentioned in the previous section (i.e., fuel volatility, temperature and evaporative control system design) on emissions from current vehicles. The section begins with a brief description of the current evaporative test procedure used in certification and changes made for the in-use EF program (i.e., the addition of commercial fuels and the switch in fuel sequence). Next, general evaporative emission results from the EF program are presented for various RVP levels with a comparison between the revised estimates and the MOBILE3 figures published in June 1984. In the following section, these revised hot-soak and diurnal emission levels are broken down into several basic components of motor vehicle evaporative emissions, based on an analysis of the vehicle test fleet. By attributing certain portions of current total evaporative losses to different sources (i.e., excess RVP, malmaintenance/defect, improper design of purge system, etc.), it is possible to estimate the effect that changes in in-use RVP or certification fuel and test procedure will have on each component and, thus, on total evaporative emissions. (The effects of the various control strategies will be outlined, in detail, for various model years in Chapter 3).

i. Test Procedure

The standard evaporative test procedure used in the certification of new vehicles is outlined in detail in Part 86 of Title 40 of the Code of Federal Regulations (40 CFR 86). Briefly, the vehicle is first drained of its fuel and refueled with Indolene (with an average RVP of 9.0 psi) to the 40-percent full level. The vehicle is then preconditioned using the Urban Dynamometer Driving Schedule (also referred to as the "LA-4" cycle), which lasts approximately 23 minutes. Under special circumstances (e.g., if the vehicle was transported via carrier instead of being driven to the test site), manufacturers can request up to two LA-4 cycles to assure adequate purging of the evaporative canister. Following preconditioning, the vehicle is stored (or "soaked") for a period of 12-36 hours before the SHED (Sealed Housing Evaporative Determination) test is conducted.

Just prior to beginning the SHED test for diurnal losses, the vehicle is drained and refueled with chilled Indolene to the 40-percent fill level.* Beginning with a fuel and tank temperature of 60°F, the fuel is heated to 84°F over a period of one hour, at which time the final HC concentration in the SHED enclosure is recorded as the total diurnal loss.

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* The fuel is chilled to about 50°F to counteract the warm fuel tank (70-75°F), which is already warmer than the lower end of the temperature excursion (60°F).

Following the diurnal test, a cold-start LA-4, followed by the first half of a hot-start LA-4 is performed, during which exhaust emissions are measured. At the completion of these tests, the engine is shut off and the vehicle is pushed into the SHED enclosure for the hot-soak test. The test vehicle remains there for one hour at an average ambient temperature of 81°F* and the increase in HC concentration is recorded and converted into a total hot-soak mass emission.

The estimation of evaporative emissions as a function of fuel volatility used to evaluate the control options examined in this study was based on data generated as part of EPA's ongoing in-use emission factor (EF) test program. This program involves the testing of in-use (privately-owned) passenger cars, selected at random from State of Michigan vehicle registration files. Prior to November 1983, in-use (privately-owned) vehicles were evaluated for hot-soak and diurnal losses only while operating on certification test fuel (Indolene) with a 9.0-psi RVP. Since then, however, the effect of fuel volatility on emissions has been examined with the addition of two commercial fuels with nominal RVPs of 11.5 psi (added in November 1983) and 10.5 psi (added in August 1984).

The test procedure used in the EF program has basically followed certification practices except for certain differences in vehicle preconditioning and, of course, the addition of commercial fuels. The in-use EF test sequences are summarized in Table 2-10. Between November 1983 and July 1984, vehicles were preconditioned over a shortened LA-4 cycle which lasted only ten minutes instead of the entire 23 minutes. Commercial fuel with an 11.5-psi RVP was added to the test sequence following all evaporative and exhaust emission tests conducted on Indolene.

In July 1984, the shortened prep cycle was dropped and the entire LA-4 cycle (used in certification) was reinstated. Also, at this time, it was concluded that the evaporative tests on 11.5-psi commercial fuel may have been unrepresentative because they were run following a battery of tests on 9-psi Indolene over which the evaporative canister was repeatedly purged. Therefore, the commercial test was begun with an essentially "unloaded" canister, which would probably bias results toward lower emissions than those experienced in the field. Further, because vehicles had been operated on 11.5-psi commercial fuel prior to arriving at EPA, it follows that the most accurate measurement of in-use emissions would be obtained by testing commercial fuel first. Therefore, the test sequence

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* The hot-soak temperature range specified in the CFR is 68-86°F.

Table 2-10

Comparison of In-Use Test Sequences

Nov. 83 - July 84	Post - July 84
1. Park indoors and/or outdoors	1. Park indoors; loosen gas cap
2. Shortened dynamometer (10-min.)	2. LA-4 dynamometer prep (23-min.)
3. Indolene evaporative tests	3. Commercial (11.5 psi) evaporative tests
4. Exhaust emission tests (HFET and short tests)	4. Mixture (10.5 psi) evaporative tests*
5. Commercial (11.5 psi) evaporative tests	5. Indolene evaporative tests
	6. Exhaust emissions tests (HFET and short tests)

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* 10.5 RVP added in August 1984.

was changed and the 11.5-psi fuel was tested first, followed by Indolene.

In August 1984, testing of the mid-range commercial fuel with an RVP of roughly 10.5 psi was added to the sequence just after the 11.5-psi fuel and before any Indolene testing. Other minor changes (initiated in July 1984) involve the storage of the vehicle prior to any evaporative tests. To avoid premature saturation of the canister prior to testing, the gas cap is loosened to allow vapors to bypass the control system and the vehicle is stored inside at a fairly constant temperature.

ii. General Test Results

Vehicle samples used in EPA's in-use EF testing both prior to and after the July 1984 test procedure changes are broken down by manufacturer in Table 2-11.* Carbureted and fuel-injected samples are outlined separately, and sample distributions are compared to 1984 market shares.

Evaporative emissions from these test vehicles are summarized in Table 2-12. Results are shown for both Indolene and commercial (11.5-psi) fuels, and are separated out by vehicle type and test procedure. The MOBILE3 emission rates published in June 1984 are from a subset of the November 1983-July 1984 tests and are listed separately for comparison. The estimates used for this analysis are listed as July 1984 - March 1986 results.

As indicated from the results shown in Table 2-12, the change in the test procedure has had mixed effects on emissions with Indolene and higher emissions with commercial fuel in all cases. (This is as to be expected from the previous discussion on the reasons behind the changes in fuel test sequence.) For fuel-injected vehicles, higher emissions also may be partially due to the higher average mileage of the vehicles being tested; the vehicles tested after July 1984 have an average mileage almost twice that of those tested previous to that time. Results of the July 84 - March 1986 testing are shown graphically in Figure 2-7, which plots revised hot-soak and diurnal emissions versus fuel RVP.

Both sets of vehicles tested show average emissions exceeding the 2-gram standard for total evaporative emissions, even while operating on Indolene: carbureted vehicles

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* The post-July 1984 vehicle sample includes vehicles tested only through March 1986, the point at which test results were "frozen" for this analysis. Vehicles tested after the cut-off date, are being tested only with two fuels of 9.0 psi and 11.5 psi RVP.

Table 2-11

In-Use EF Vehicle Sample Distribution

	Carbureted			Fuel-Injected		
Manufacturer	Nov. 83-July 84	July 84-March 86	1984 Market Share	Nov. 83-July 84	July 84-March 86	1984 Market Share
GM	31(33%)	45(29%)	46%	57(74%)	75(46%)	42%
Ford	38(41%)	40(24%)	13%	9(12%)	38(23%)	25%
Other Domestic*	12(13%)	32(21%)	11%	--	25(15%)	11%
Toyota	2(2%)	14(9%)	4%	--	13(8%)	10%
Nissan	3(3%)	15(10%)	5%	3(4%)	8(5%)	9%
Other Imports**	7(8%)	9(5%)	21%	8(10%)	4(3%)	3%
Total	93(100%)	155(100%)	100%	77(100%)	163(100%)	100%

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* AMC, Chrysler, VWA.

** Honda, VWG, Mitsubishi, Toyo-Kogyo, Audi, Renault, Fuji.

Table 2-12

Comparison of Evaporative EF Test Data from Non-Tampered Vehicles (g/test)

Indolene (RVP = 9.0 psi)

Test Period	Technology	N	Mileage	Diurnal	Hot-Soak
Nov 83 - July 84	Carb.	93	45000	4.16	2.19
	Fuel-Inj.	77	20000	1.64	0.96
Published MOBILE3*	Carb.	53	60000	4.22	2.74
	Fuel-Inj.	62	20000	2.21	1.12
July 84 - March 86**	Carb.	155	58000	2.60	2.57
	Fuel-Inj.	163	35000	1.67	0.88

Commercial Fuel (RVP = 11.5 psi)

Test Period	Technology	N	Mileage	Diurnal	Hot-Soak
Nov - July 84	Carb.	93	45000	8.64	3.29
	Fuel-Inj.	77	20000	2.33	1.28
Published MOBILE3*	Carb.	53	60000	9.31	3.98
	Fuel-Inj.	62	20000	3.13***	1.55
July 84- March 86**	Carb.	155	58000	10.33	4.26
	Fuel-Inj.	163	35000	8.51	2.70

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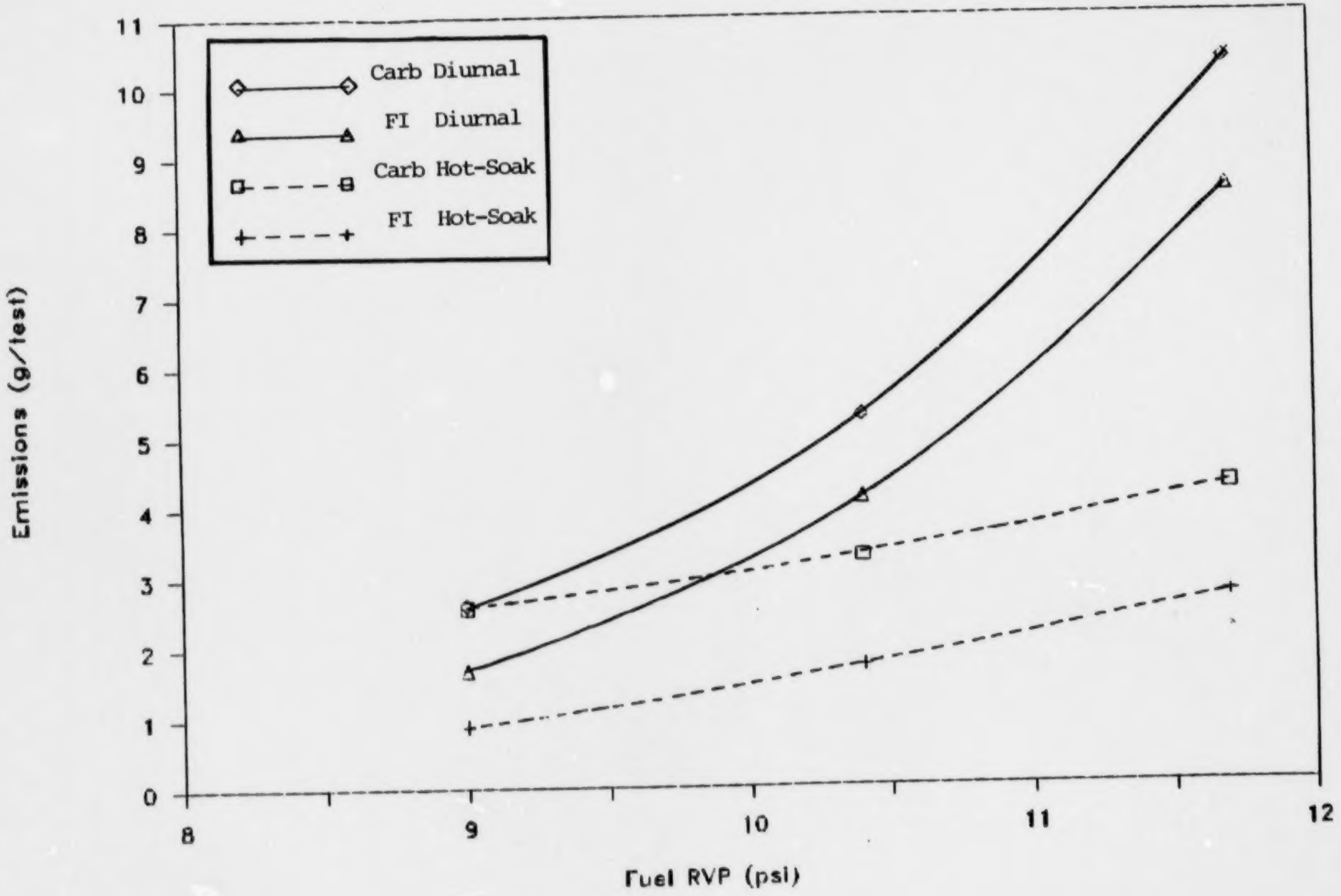
* The MOBILE3 results are from a subset of the Nov. 83 - July 84 data pool.

** Revised MOBILE3 estimates, used in this study.

*** This is the average of actual test results. However, due to uncertainties associated with the low mileage, the value for carbureted vehicles was also used for fuel-injected vehicles in MOBILE3.

Figure 2-7

Non-Tampered Evap. Emissions vs. RVP



averaging 5.17 grams/test and fuel-injected vehicles averaging 2.55 grams/test. When tested on 11.5-psi commercial fuel, these evaporative emissions are much larger: 14.59 grams/test for carbureted vehicles and 11.21 grams/test for fuel-injected vehicles. The possible causes of the excess evaporative emissions are the subject of discussion in the following section.

iii. Components of Excess Motor Vehicle Evaporative Emissions

For purposes of analysis, it is useful to segregate the evaporative emission excess described above according to its probable causes. Using EF test data, these four basic categories were chosen as: 1) effect of insufficient design capacity/purge, 2) effect of malmaintenance and defects, 3) effect of excess RVP, and 4) effect of evaporative system tampering. The causes and magnitude of each of these effects (for current vehicles) are detailed below. More detailed information on the methodology used to separate these four sources is provided in Appendix 2-A.

Insufficient Design Capacity/Purge

Even with properly functioning evaporative emission control systems, many current vehicles fail to meet the 2-gram standard on Indolene. This is primarily seen in carbureted vehicles which average 3.12 grams/test when there are no apparent malfunctions.* Conceivably, this failure could be due to an insufficient capacity to store or purge vapors inherent in the system design. It may also be valid to attribute some of these excess emissions to the temporary effects of high RVP fuels on charcoal working capacity.

The plausibility of insufficient design capacity and purge is evident from the limitations of the evaporative emission test procedure and certification process. To be certified, a vehicle must meet the standard after applying an additive deterioration factor to low mileage emission test data. Also, MSAPC Advisory Circular No. 50A states that vehicles should be able to pass the evaporative emission test when starting the test sequence with a saturated canister. (Many EF vehicles are probably received in this condition.) This means that purge systems should be designed to completely purge a loaded canister with the LA-4 prep cycle. However, there is no requirement for this in the certification test procedure. Thus, it is possible that a certification vehicle, as currently designed, would fail if it began the test with a saturated canister.

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* As shown in Appendix 2-A, Table 2-A-2, for "problem-free" vehicles (to be explained in the next few paragraphs).

The derivation of the magnitude of the insufficient design capacity/purge effect is detailed in Appendix 2-A. The general concept involved was to compare the average emission levels of the "problem-free" vehicles, as defined in Table 2-13, with the standard level of 2 grams/test for total evaporative emissions. The difference between the two levels was assumed to be due to the emission control system design. This effect is not seen in fuel-injected vehicles, but averages 1.12 grams/test for carbureted light-duty vehicles. The insufficient design capacity/purge effect is noted here because it presumably would be eliminated for new vehicles by revising the evaporative emission test procedure to require that a vehicle begin the test with a saturated canister.

Malmaintenance and Defects

Non-tampered vehicles with the maintenance problems and hardware defects listed in Table 2-13 (tampering is considered separately below) will generally have higher evaporative emissions than well-maintained vehicles. These problems can lead to either a partial increase in emissions (e.g. from a dirty canister filter) or to completely uncontrolled emissions (e.g., from an inoperative canister purge solenoid or valve). On average, excess emissions would not be expected to be as high as the uncontrolled emission baseline because some purging could still occur. This is different from the case of tampering where complete system disablement is generally the result.

The magnitude of the effect of malmaintenance and defects for current vehicles operating on Indolene is estimated by considering the difference between the non-tampered EF vehicle sample average and the problem-free vehicle sample average tested on Indolene. Inherent in this calculation is the assumption that the EF sample has a representative malmaintenance and defect rate. Table 2-14 compares the malmaintenance and defect rate for various vehicle data bases. For carbureted vehicles, the malmaintenance and defect rate from EF cars tested since July 1984 (35 percent) is within the range and essentially equal to the average of all other available data samples. For fuel-injected vehicles, the newer EF sample has a rate slightly higher than the older EF sample (e.g., 12 percent in the more recent sample versus five percent in the older sample). However, this is probably due to the fact that the fuel-injected vehicles in the old EF sample averaged fewer total miles on their odometers than those in the current sample (20,000 vs. 35,000). Overall, then, the malmaintenance and defect rates in the July 1984 - March 1986 EF sample appear representative.

Table 2-13

Conditions Excluding Vehicles From Problem-Free Sample

I. Fuel System

  A. Carburetor Assembly
    1. Loose on Manifold
    2. Leaks Fuel
    3. Exceptionally Dirty

  B. Fuel Injection Components
    1. Injectors Leaking

II. Evaporative System

  A. Canister
    1. Saturated with Fuel
    2. Broken
    3. Missing*

  B. Canister Filter
    1. Dirty
    2. Saturated with Fuel
    3. Missing

  C. Canister Purge Solenoid/Valve
    1. Leaks Vacuum
    2. Sticking
    3. Inoperative
    4. Missing*
    5. Disconnected*

  D. Hoses, Lines, Wires
    1. Vacuum Line Plugged
    2. Vacuum Line Disconnected*
    3. Vacuum Line Damaged
    4. Vacuum Line Misrouted*
    5. Vent Line Damaged
    6. Vent Line Disconnected*

  E. Other
    1. EFE TVS Stuck Open/Closed
    2. Non-OEM Gas Cap
    3. Bowl Vent Control Valve Always Open/Closed
    4. VCV Vacuum Control Valve Inoperative
    5. Gas Cap Leaks
    6. Sending Unit Gasket Leaking
    7. Fuel Tank Rollover Valve Leaking
    8. Air Cleaner Assembly Gasket Broken/Missing
    9. EFE Control Switch Missing*
    10. Gas Cap Missing*

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* Considered to be tampering.

Table 2-14

Malmaintenance and Defect Rate Comparison

Sample	Carbureted Sample Size	Carbureted Defect Rate	Fuel Injected Sample Size	Fuel Injected Defect Rate
EF (new)*	155	35%	163	12%
EF (old)**	93	44%	77	5%
SwRI[24]	27	26%	--	--
API (NIPER)[25]	19	11%	32	13%
API (ATL)[26]	28	25%	10	0%
Average***	--	35%	--	10%

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* Vehicles tested on three fuels w/LA-4 prep, commercial fuel first; July 1984-March 1986.

** Vehicles tested on two fuels w/10-minute prep, Indolene fuel first; November 1983-July 1984.

*** Sample-size weighted.

While the above methodology appears satisfactory for estimating the magnitude of the malmaintenance/defect effect for vehicles operating on 9-psi Indolene, it is expected that the effect would increase with the level of in-use RVP. The same would be true for a tampered vehicle. Basically, if excess emissions are being released from the canister or elsewhere, increased vapor loadings that result from higher in-use RVPs will lead to increased emissions. While redesigning vehicles for higher RVP fuel should lower emissions when the control system is fully operable, the effect of malmaintenance or a defect would be expected to be independent of the RVP for which the vehicle was designed and dependent only on the RVP of the fuel actually used. Estimation of the magnitude of this effect at various RVPs is described in detail in Appendix 2-A.

While the insufficient design/purge and excess RVP effects (discussed below) are assumed to be totally eliminated in new vehicles via changes to certification fuel and test procedure, the malmaintenance/defect effect can only be controlled through reduction of in-use fuel volatility or possibly through an effective evaporative system inspection and maintenance program (See Appendix 6-B).

Excess RVP Effect

The excess RVP effect is defined as the emissions impact of operating vehicles on a fuel of higher volatility than that for which their evaporative control systems have been designed. Canisters and purge systems on current vehicles are designed to meet the 2-gram evaporative standard when operated on 9.0 psi Indolene over the standard certification test procedure. However, as discussed previously in this chapter, the RVP of current in-use gasoline in many of the ozone non-attainment areas of the country is significantly higher than 9.0 psi. Because of the higher volatilities, more evaporative HCs are emitted than the canister can accommodate, which results in canister saturation and "breakthrough" of HC vapors to the atmosphere.

The magnitude of this excess RVP effect can be calculated by first subtracting total average emissions of the problem-free sample on Indolene from those on commercial fuel. The excess RVP effect is assumed to be at least partially eliminated for new vehicles if certification fuel RVP is raised to a level equal to or greater than in-use fuel RVP. (Ambient temperature effects could create a situation where the excess RVP diurnal effect is not completely eliminated.) However, for vehicles certified prior to any change in certification fuel RVP (i.e., 1990 in this analysis), the excess RVP effect will remain and be dependent upon in-use RVP.

Tampering Effect

Intentional system disablement also contributes toward excess evaporative emissions. EPA's in-use EF sample is not thought to have a representative number of tampered vehicles, since those who tamper with their emission controls may be reluctant to lend their vehicles to EPA for testing. The EF sample is also relatively small due to the high cost of emission testing. For these reasons, tampering rates to be used in emissions modeling are developed from EPA tampering surveys involving thousands of vehicle inspections. Those conditions considered as tampering are primarily disconnected, misrouted or missing hoses, missing canisters and missing fuel caps (as indicated previously in Table 2-13).

Because emissions from tampered vehicles are not developed from the EF sample, the MOBILE3 program accommodates them separately. Tampering incidence rates are developed from survey data and excess emissions are determined from emission tests on completely disabled systems. Since the original MOBILE3 estimates were published in June 1984, additional tampering data has become available that has allowed improvement over the June 1984 estimates. These revisions to the MOBILE3 tampering estimates are discussed below.

The original MOBILE3 LDV tampering incidence rates published in June 1984 were based on a linear regression of tampering frequency versus mileage using the results of EPA's 1982 Tampering Survey.[27] For LDTs and HDVs, the rate of increase of tampering with mileage for LDVs was applied to the average LDT-sample tampering frequency and vehicle mileage, because the LDT sample was too small to derive a change in tampering over time and no HDVs were surveyed. The zero-mile tampering rates, however, were developed from the LDT sample; these LDT zero-mile rates were also used for HDVs.

As mentioned above, updated EPA survey results from 1983, 1984 and 1985 have since become available, so these data were added to the 1982 tampering data used to develop the tampering estimates used for this analysis.[28,29,30] The resulting information was sufficient to develop separate tampering rate estimates for both LDVs and LDTs; the HDV rates were still assumed to be the same as those for LDTs. Additional revisions to the tampering estimates include the designation of vehicles with misrouted hoses and missing fuel caps as tampered vehicles.* Since these conditions were not considered as tampering in the June 1984 version of MOBILE3, previously estimated effects of tampering may have been somewhat understated. Plots of the revised tampering rates versus mileage for LDVs and LDTs are shown, respectively, in Figures 2-8 and 2-9.

---

* As misrouted hoses and missing fuel caps could be unintentional, there remains some question as to whether they should be considered "tampering" or "malmaintenance." However, as these conditions were not felt to be properly represented in the EF sample, they are currently regarded as tampering.

One possible form of tampering/malmaintenance that still remains to be investigated is the use of replacement gas caps not meeting the same specifications as the original gas cap (referred to as non-OEM (original equipment manufacturer) gas caps). Such gas caps may not seal properly and could result in either partially or completely uncontrolled emissions. The extent of their use and their effect on emissions is currently being investigated.

In addition to revising tampering incidence rates, the emission rates for tampered vehicles have also been modified by supplementing the pre-June 1984 data with more recent data and by incorporating emission excesses associated with missing fuel caps. With certain exceptions, it is assumed that all types of tampering result in completely uncontrolled emissions. A case in which this assumption may not be strictly valid is for the disconnection of a carburetor bowl vent line at the carburetor end (i.e., not at the canister). In this case, only hot-soak emissions would be uncontrolled. However, because the tampering survey does not make this distinction, a better estimate is not available at this time.

The uncontrolled evaporative emission rates used to quantify the tampering effects are based on SHED testing of vehicles with removed canisters and/or fuel caps. These are summarized in Table 2-15, which also shows the increase with in-use fuel RVP. Several assumptions that were made in deriving these emission rates are described below.

First, with respect to diurnal losses, the effect of fuel cap removal is assumed to be the same as canister removal for both carbureted and fuel-injected vehicles, since diurnal emissions result entirely from the fuel tank. Also, diurnal emissions from fuel-injected vehicles with either missing gas caps or canisters is assumed to be the same as those from uncontrolled carbureted vehicles (for which more data exist). Again, diurnal emissions occur entirely from the fuel tank where the two technologies do not differ. Also, the fuel tank volumes of the two vehicle types do not generally differ.

Second, with respect to hot-soak emissions from fuel-injected vehicles, fuel cap removal is assumed to result in completely uncontrolled hot-soak emissions. A properly assembled fuel injector should emit little, if any, during a hot soak, leaving the fuel tank as the primary source of

Figure 2-8

LDV Tampering Rates

MOBILE3 and New Surveys

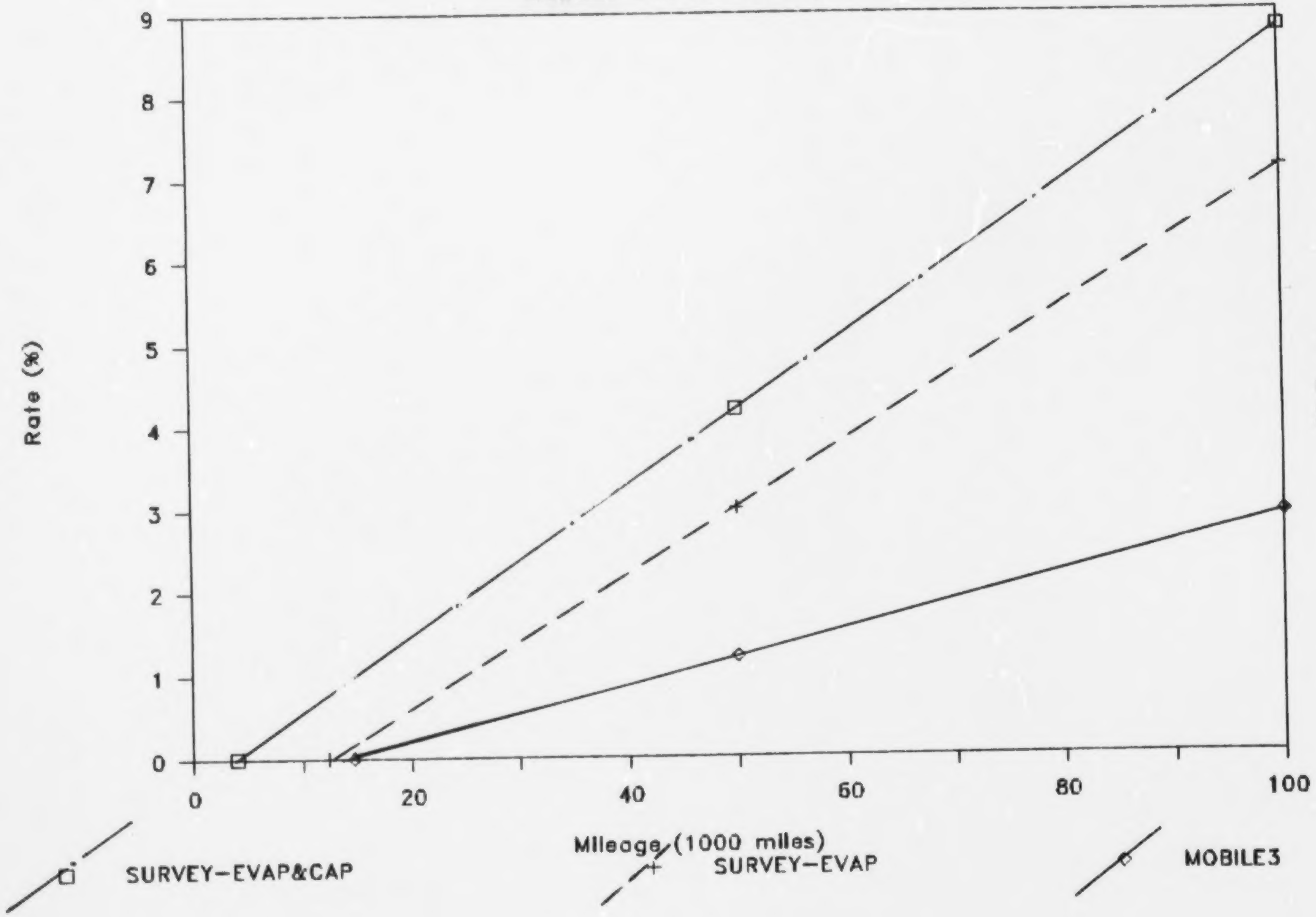
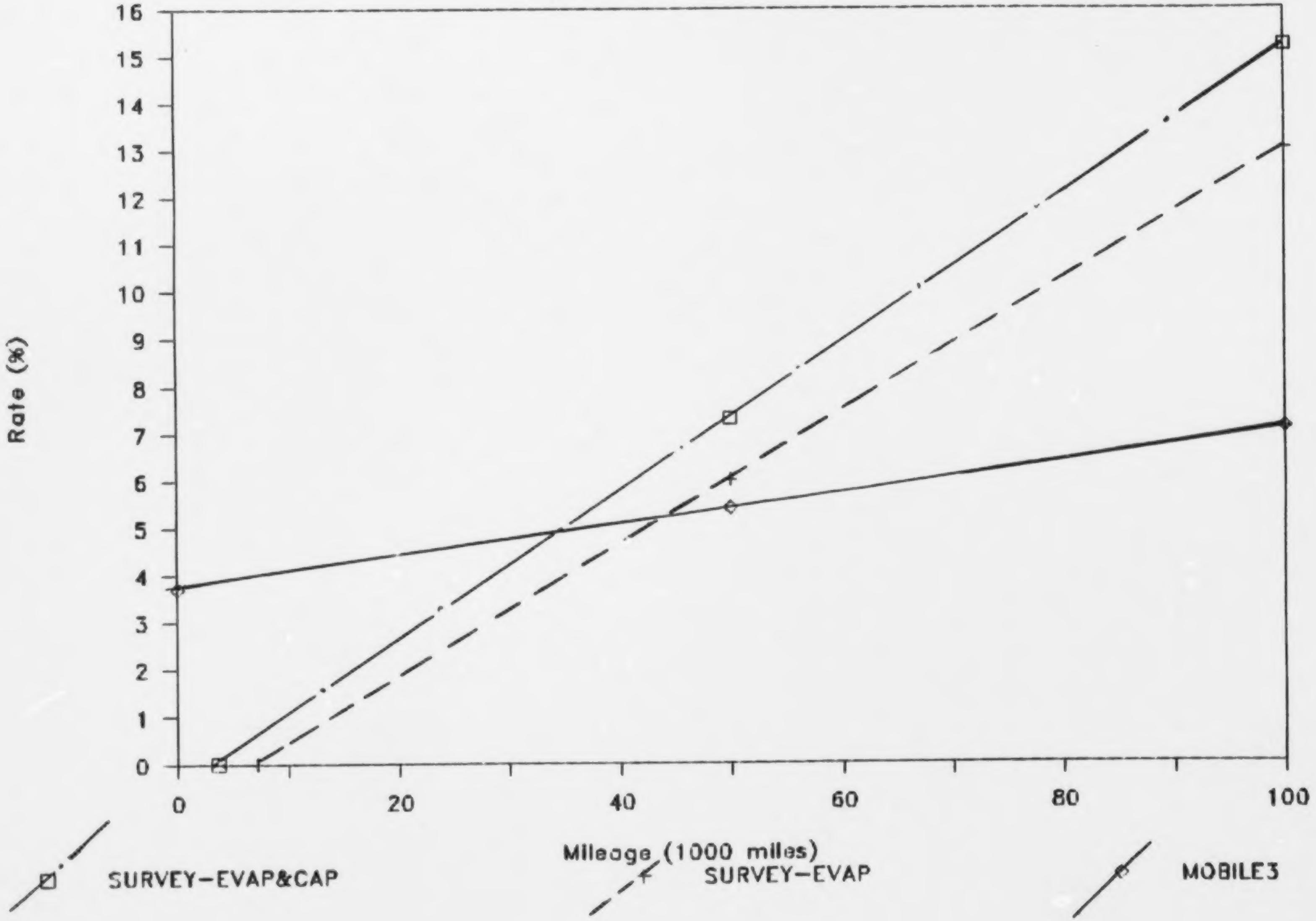


Figure 2-9



LDT Tampering Rates

MOBILE3 and New Surveys

Table 2-15

Uncontrolled Evaporative Emissions (g/test) from Tampered Vehicles vs. RVP*

Vehicle Type	Model Year	Fuel System	Canister Disconnects				Gas Cap Removal			
			--9.0 psi--		-11.5 psi**-		--9.0 psi--		-11.5 psi**-	
			H.S.	Dnl.	H.S.	Dnl.	H.S.	Dnl.	H.S.	Dnl.
LDV	pre-71	All	14.67	26.08	22.45	47.99	14.67	26.08	22.45	47.99
and	71	All	14.67	26.08	22.45	47.99	10.91	26.08	16.15	47.99
LDT_1	72-77	All	14.67	20.90	22.45	35.45	10.91	20.90	8.98	35.45
	78-80	All	13.29	16.32	18.50	25.11	2.32	16.32	3.79	25.11
	81+	Carb	10.36	15.40	17.47	27.61	2.46	15.40	4.27	27.61
		Finj	5.20	15.40	9.00	27.61	5.20	15.40	9.00	27.61
LDT_2	pre-79	All	18.08	42.33	27.66	77.89	18.08	42.33	27.66	77.89
	79+	Same as LDV, LDT_1								
HDV	pre-85	All	18.08	42.33	27.66	77.89	18.08	42.33	27.66	77.89
	85+		14.67	26.08	23.31	39.87	3.92	26.08	6.81	39.87

---

* Figures presented are for low altitudes; high-altitude correction factors are as follows: 1) LDV -- pre-1977 = 1.3, 1977 = 1.0, 1978-81 = 2.59, 1982-83 =1.3, 1984+ = 1.0; 2) LDT_1, LDT_2 and HDV -- all model years = 1.3.

** Values for uncontrolled emissions between 9.0 and 11.5 psi can be calculated via linear interpolation of the RVP for hot-soak emissions and the UDI for diurnal emissions (except for gas cap removal carbureted hot-soak emissions which are the same as non-tampered carbureted hot-soak emissions).

emissions. Data on thirteen fuel-injected vehicles confirm this. Hot-soak emissions using Indolene with the gas cap removed and those with the canister removed were essentially identical at just over 4 grams/test, where controlled emissions were below one gram/test.[31] Emissions using commercial fuel without a canister were only slightly higher than those without a gas cap. Thus, this assumption appears to be valid for fuel-injected vehicles. However, for carbureted vehicles, the increase in hot-soak emissions due to fuel cap removal is expected to be less than totally uncontrolled hot-soak emissions because the carburetor bowl contributes to, and probably is the major source of, hot-soak losses from these vehicles. Since data are not available to precisely predict the degree to which hot-soak emissions from carbureted vehicles would increase with fuel cap removal, it will be assumed that the carburetor bowl dominates and that hot-soak emissions do not increase. Thus, the values presented in Table 2-15 for hot-soak emissions from carbureted vehicles with missing fuel caps are the same as those for non-tampered carbureted vehicles (i.e., 2.57 and 4.26 g/test for 9.0-psi and 11.5-psi RVPs, respectively, as shown in Table 2-12).

As explained in Appendix 2-A, the tampering offsets used in this analysis were calculated by subtracting the average non-tampered vehicle emissions from the uncontrolled emission levels. These offsets were then incorporated into the EF runs at the tampering incidence rates developed from the survey data previously discussed. These offsets represent extreme increases in evaporative emissions, reaching combined hot-soak and diurnal levels of 20-30 grams/test for 11.5 RVP fuel. (Tampering offsets are shown in Appendix 2-A for light-duty and heavy-duty vehicles in Tables 2-A-6 and 2-A-8, respectively.)

Summary

Based on the above discussions, motor vehicle evaporative emissions can be divided into several different categories. The first consists of emissions from properly-designed and operated vehicles assumed to emit at the standard; therefore, none of the control strategies (to be detailed in the last section of this chapter) will reduce this portion. However, the four components of current excess motor vehicle emissions will be addressed in the remainder of this study.

The first -- insufficient design of the purge system -- could be addressed via changes to the certification test procedure. The excess RVP effect could theoretically be reduced or eliminated through the reduction of in-use fuel RVP and/or the revision of certification fuel specifications. The effects of the remaining two sources of excess evaporative losses (i.e., malmaintenance/defects and tampering) probably cannot be totally eliminated, but could be significantly reduced if in-use RVP were controlled to lower levels or an effective inspection and maintenance program for evaporative systems could be developed and implemented.

The extent to which each of these five sources contribute to total motor vehicle evaporative losses -- and to total non-methane hydrocarbon (NMHC) inventories -- will be explained in Chapter 3. There, future total NMHC inventories will be broken down into stationary source emissions (separated into bulk storage, Stage I, and other) and motor vehicle losses (divided into exhaust HC, refueling, and evaporative HC losses).

c. Development of a Motor Vehicle Evaporative Emissions Model

Evaporative emissions are affected by many variables, such as type of fuel metering system, RVP, ambient temperature, percent full of tank, and tank size, among others. However, the great majority of evaporative emissions data are measured at the federal test procedure (FTP) conditions which are not completely representative of all in-use conditions, specifically temperature, RVP, and the fill level of the tank, which vary considerably throughout the country. To better represent in-use evaporative emissions, a model should take into account the geographical-specific nature of evaporative emissions. The purpose of this section is to present the motor vehicle evaporative emissions model developed for this analysis and compare the model to currently available emissions data and evaporative models. The first section will describe the diurnal evaporative emissions model and attempts to verify the model, and the second section will describe the hot-soak model.

i. Diurnal Model

Uncontrolled diurnal emissions originate from the fuel tank and are primarily a function of the properties of the fuel in the gas tank, the diurnal temperature swing, and the amount of fuel in the tank. Controlled diurnal emissions measured in a SHED test are the hydrocarbons which pass through the evaporative control system and are not trapped by the charcoal canister. In addition to the factors affecting uncontrolled emissions, controlled diurnal emissions are a function of the capacity of the canister, the type of charcoal in the canister, the amount of hydrocarbons loaded on the canister before the beginning of the test, and other vehicle-related parameters. Uncontrolled diurnal emissions can be predicted readily; however, the evaporative control systems vary widely from manufacturer to manufacturer, and also model to model and do not lend themselves to being modeled accurately.

The diurnal emissions model developed for this analysis first predicts the uncontrolled diurnal emission potential at specified in-use or test conditions analytically, and then uses empirically-derived relationships between uncontrolled and controlled diurnal emissions to predict the latter at the test conditions of interest. (Appendix 2-A presents the derivation of these relationships.) The key assumptions of the model are that controlled emissions increase monotonically with uncontrolled emissions, and that controlled emissions can be related to an uncontrolled emissions potential. Based on the characteristics of the evaporative control system (charcoal properties and purge air effects), the assumptions would be expected to be valid.

The uncontrolled diurnal emissions potential is based on an equation developed by D.T. Wade in 1967.[32] The equation relies on changes in actual fuel vapor pressure, the Ideal Gas Law, and the processes occurring in a vehicle's fuel tank to predict uncontrolled diurnal losses from a fuel tank as a function of fuel properties, temperature conditions, and percent full of tank.

Wade's equation can be used to predict absolute uncontrolled diurnal losses (i.e., grams of HC emitted from the fuel tank) for any given set of conditions; however, its use here was to predict relative losses and not absolute values. More specifically, Wade's equation was used here to calculate a relative index of theoretical uncontrolled diurnal emissions which could be related to measurements of controlled diurnal emissions under various conditions to produce a diurnal emissions model. The equation used for uncontrolled diurnal losses is as follows:

$$G = 227\,(W)\left(\frac{520}{(690 - 4M)}\right)\left[\frac{p_1}{(P_t - p_1)} + \frac{p_2}{(P_t - p_2)}\right]\left[\frac{(P_t - p_1)(V_1)}{T_1} - \frac{(P_t - p_2)(V_2)}{T_2}\right]$$

where:

G = Weight hydrocarbon lost, g
W = Fuel density, lb/gal
M = Molecular weight of hydrocarbon vapor, lb/lb mole at average liquid temperature
p = Vapor pressure of gasoline, psia, at liquid tempertemperature corresponding to T
P = Total pressure, psia
V = Volume of vapor space, cu ft
T = Temperature, R

Subscripts:

t = Tank
1 = Initial state
2 = Final state

The uncontrolled diurnal index (UDI) was calculated as the ratio of G_{test} (using various temperatures, RVPs, and percent fill levels) to G_{cert} (based on the 60-84°F diurnal test with a 40 percent full tank and the RVP of the fuel for which the vehicle was certified). Exhibit 2-1 is a listing of the computer program which calculates the UDI for different in-use and certification RVPs, temperatures, and fill levels.

The equation for fuel density is based on a linear regression of fuel density versus RVP from MVMA fuel surveys. The equation for molecular weight and the method of predicting vapor pressures are based on information from the Wade report. The size of the vapor space assumes an average gasoline tank size of 16 gallons with a vapor space of two gallons when the tank is "full." The size of the vapor space at the beginning of the diurnal test is assumed to be equal to the size of the vapor space at the end of the diurnal test. The tank is assumed to be at atmospheric pressure. Atmospheric pressure is assumed to be 14.7 psi unless the city has been formally designated as high altitude (greater than 4,000 feet above sea level), in which case the atmospheric pressure is assumed to be 12.5 psi.

Table 2-16 contains the UDIs calculated at various in-use or test conditions for varying certification fuel RVPs. The UDIs are shown for comparison purposes only. The inputs used in the diurnal model for MOBILE3 are based on city-specific RVPs, temperatures, and the certification fuel of the control scenario (see Tables 3-1, 3-2, and 3-5 for a list of the city-specific inputs). The UDI is used by MOBILE3 to calculate the diurnal emission factors as described in Appendix 2-A.

In an attempt to verify the evaporative emissions model with other available diurnal emissions information, the model was compared to a more sophisticated GM model of uncontrolled diurnal emissions, Automotive Testing Laboratories (ATL) diurnal emissions data, and some EPA emission data at varying tank fill levels.

The method used by GM to calculate uncontrolled diurnal emissions is similar to the EPA model.[33] However, a more complex procedure was used to predict the gasoline vapor pressure at different temperatures based on the chemical composition of the gasoline. The GM model is compared to the

```
      FUNCTION CALIND(RVP1,RVP2)
C
C  CALIND uses passed in fuel RVP levels, minimum and maximum fuel tank
C  temperatures and fleet average percent of fuel tank filled to estimate
C  the "uncontrolled diurnal index".  Subsequently, the diurnal evaporative
C  emission factor will be calculated as a function of this "index".
C
C  Called by LOCAL
C
C  Input on call:
C
C    parameter list:
C    RVP1 - RVP to be evaluated
C    RVP2 - RVP to be normalized, eg., certification fuel RVP
C
C    common blocks:
C    /CITCIN/ KREJN
C    /CITPAR/ TEMMIN,TEMMAX
C    /RVPNAT/ PFUL
C
C  Output on return:
C
C    function: CALIND
C
C  Local array subscripts :
C
C   T(2)     -  T ( LT )
C   VPPR(2)  -  VPPR ( LT )
C
C  Local variable / array dictionary:
C
C  Name   Type              Description
C  ------ ----  -----------------------------------------------------
C  ARPR    R    Atmospheric pressure, if KREJN = 1, then ARPR = 14.696
C  PFTP    R    Percent of fuel tank filled under FTP (always 40%)
C  DENSTY  R    Fuel density, a function of RVP
C  VPSP    R    Vapor Space in cubic ft, a function of PFUL
C  T(LT)   R    Incremental fuel temperature in F
C  TT      R    Maximum temperature
C  VP100   R    Vapor pressure at 100F, a function of RVP
C  C       R    Constant, used to calculate A100
C  X       R    Coefficient used to calculate A100, a function of VP100
C  A100    R    Coefficient used to calculate A
C  A       R    Coefficient used to calculate VPPR(I)
C  WTM     R    Molecular weight, a function of RVP and fuel temp
C  VPPR(I) R    Vapor pressure at T (low/high temperatures)
C  TP1     R    First coefficient for uncontrolled diurnal equation
C  TP2     R    Second coefficient for uncontrolled diurnal equation
C  TP3     R    Third coefficient for uncontrolled diurnal equation
C  G       R    Weight HC loss in grams under T(I), RVP1, and PFUL
C  GFTP    R    Weight HC loss in grams under FTP (60-84F, 40% Full, RVP2)
C
C  Notes:
C
C  CALIND is G/GFTP, each of which is a function of temperature increment
C  (from TEMMIN to TEMMAX), RVP fuel and PFUL (percent tank filled)
C
C  CALIND was added for In-House Version 09.
```

```
C
C
      COMMON /CITCIN/ CIGAS1,CIGAS2,CIETH1,CIETH2,ICERSW,KREJN
      COMMON /CITPAR/ CITNAM(4),TEMMIN,TEMMAX,FRETH,FRMETH,FRGAS
      COMMON /RVPNAT/ IUSESY,ICERSY,RVPCER,RVPLIM(2),PFUL
C
      DIMENSION T(2),VPPR(2)
C
      DATA  PI/3.14159/,PFTP/40.0/
C
      ARPR=14.696
      IF(KREJN.NE.1) ARPR=12.5
      CINDEX=0.0
      GFTP=0.0
C
C  First J pass computes denominator GFTP.  Second pass repeatedly computes
C  numerator G, divides it by GFTP and adds it to accumulator CINDEX,
C  until T(2) exceeds TT.
C
      DO 50 J=1,2
      RVP=RVP1
      IF(J.EQ.1) RVP=RVP2
C
C  Calculate fuel density for given RVP.
C
      DENSTY=6.4-0.01977*RVP
C
C   Calculate vapor space under given PFUL.
C
      IF(J.EQ.1) PF=PFTP
      IF(J.EQ.2) PF=PFUL
      VPSP=2.4062-0.02139*PF
C
C  Calculate vapor pressure at 100 (VP100) for given RVP.
C
      VP100=1.0223*RVP
     *    +(0.0357*RVP)/(1.0-0.0368*RVP)
C
C  Calculate A100 according to VP100.
C
      IF(VP100.LT.14.18) GOTO 10
      C=80.861
      X=0.11*COS((4.0*VP100-9.0)*PI/14.0)
     *  +5.4*ALOG(VP100)
      GOTO 20
C
   10 C=66.561
      X=0.12*COS((VP100-6.0)*PI/4.0)
     * -0.21*SIN(2.0*PI/7.5*(VP100-4.0))
C
   20 A100=C-12.822*VP100
     *       +1.3291*VP100**2
     *       -0.07991*VP100**3
     *       +1.9017E-03*VP100**4-X
C
      T(1)=TEMMIN
      IF(J.EQ.1) T(1)=60.0
      TT=TEMMAX
      IF(J.EQ.1) TT=84.0
      T(2)=T(1)+1.0
C
C  Iteration starts here.
C
   30 CONTINUE
C
C  Calculate molecular weight.
C
      WTM=69.69-1.274*RVP
     *         +0.059*(T(1)+T(2))/2.0
C
C  Calculate vapor pressures.
C
      DO 40 I=1,2
      A=A100+(100.0-T(I))
     *     *((262.0/(A100/6.0+560.0))-0.01328)
C
      VPPR(I)=14.696
     *        -0.53059*A
     *        +7.6961E-03*A**2
     *        -5.4907E-05*A**3
     *        +1.7044E-07*A**4
   40 CONTINUE
C
C  Apply uncontrolled diurnal equation.
C
      TP1=VPSP*118040.0*DENSTY/(690.0-4.0*WTM)
      TP2=VPPR(1)/(ARPR-VPPR(1))
     *   +VPPR(2)/(ARPR-VPPR(2))
      TP3=(ARPR-VPPR(1))/(T(1)+460.0)
     *   -(ARPR-VPPR(2))/(T(2)+460.0)
      G=TP1 * TP2 * TP3
C
C  Next step depends on loop 50 counter J: 1 = calc GFTP, 2 = calc CINDEX.
C
      IF(J.EQ.1) GFTP=GFTP+G
      IF(J.EQ.2) CINDEX=CINDEX+G/GFTP
C
      T(1)=T(1)+1.0
      T(2)=T(2)+1.0
      IF(T(2).LE.TT) GOTO 30
   50 CONTINUE
C
      CALIND=CINDEX
C
      RETURN
      END
```

Table 2-16

UDIs Under Various Test Conditions

Certification RVP (psi)	Test RVP (psi)	Tank % Full	T_1 (°F)	T_2 (°F)	UDI
9.0	9.0	40	60	84	1.0000
	9.5				1.1454
	10.0				1.3094
	10.5				1.4961
	11.0				1.7104
	11.5				1.9581
10.0	10.0	40	60	84	1.0000
	10.5				1.1426
	11.0				1.3062
	11.5				1.4954
10.5	10.5	40	60	84	1.0000
	11.0				1.1432
	11.5				1.3088
11.5	11.5	40	60	84	1.0000

EPA model by predicting a GM Uncontrolled Diurnal Index at various temperature and RVP conditions. The GM model was run at several in-use and test conditions and the GM Uncontrolled Diurnal Index is compared to the UDI in Table 2-17.[34] The percentage difference between the two indices at the different conditions is from only -five percent to +three percent. This comparison shows EPA's simpler method of predicting vapor pressure, and subsequently the UDI, does not lead to errors of more than five percent compared to the more complex GM model. However, had the diurnal emission data been correlated versus the GM diurnal emission potential instead of the UDI, the effect on emissions would be eliminated.

GM conducted laboratory experiments to measure evaporative vapor losses in an attempt to verify their model. The percentage difference between the predicted and measured losses were less than three percent. Most of the tests were conducted with alcohol blends which are even more complicated to model than straight gasolines.

The ATL emissions data were obtained as part of an EPA-sponsored test program measuring diurnal and hot-soak losses at various temperatures and RVPs.[23] The complete test matrix consisted of the following:

Parameter	Test Points
Gasoline RVP	9.0, 10.4, 11.8 psi
Diurnal Starting Temperature	60°, 68°, 75°F
Diurnal Temperature Change	+15°, +20°, +24°F
Hot-Soak Temperature	70°, 82°, 95°F

Emissions data from three carbureted and three fuel-injected vehicles which were available at the time of the analysis were averaged for the comparison. Table 2-18 contains the average diurnal emissions at the various diurnal temperatures and RVPs. Table 2-19 lists the UDIs associated with the diurnal test conditions.

The average diurnal emissions were plotted versus the UDI and are shown in Figures 2-10 and 2-11 for the carbureted and fuel-injected vehicles, respectively. The emissions at each RVP at diurnal temperatures between 60-84°F are highlighted with solid squares. Two conclusions can be drawn from these figures; one, controlled diurnal emissions are a function of UDI, and two, the three emission points tested at 60-84°F (FTP temperature conditions) predict the trend in controlled emissions as well as the entire data base for UDIs below 4.0, the upper limit of the majority of in-use conditions. These two assumptions are the basis for the diurnal emissions model based on the three EF test data points.

Table 2-17

Comparison of GM Uncontrolled Diurnal Index to UDI

Conditions or City	RVP (psi)	T_1 (°F)	T_2 (°F)	GM Uncontrolled Diurnal Index	UDI*
FTP	9.0	60	84	1.000 (-)	1.000
FTP	10.4	60	84	1.503 (+3%)**	1.457
FTP	11.7	60	84	2.078 (+1%)	2.068
New York	11.5	72	92	2.696 (-3%)	2.783
Chicago	11.9	77	95	3.516 (-5%)	3.714
Philadelphia	11.5	62	87	2.304 (-2%)	2.344
Detroit	12.0	66	87	2.446 (-1%)	2.472
Boston	11.5	73	97	4.046 (-5%)	4.248
Wash., D.C.	11.5	62	85	1.991 (-1%)	2.016
Miami	11.3	81	96	2.784 (-3%)	2.865
Houston	10.5	76	93	1.958 (+1%)	1.945
Pittsburgh	12.1	64	87	2.655 (-1%)	2.672
Connecticut	11.5	72	90	2.266 (-2%)	2.321

---

* Based on a 40% full tank.

** Percentage difference between UDI and GM Uncontrolled Diurnal Index.

Table 2-18

Average ATL Diurnal Emissions[23]

Fuel Metering System	No. of Vehicles	RVP (psi)	Starting Temp (°F)	Diurnal Emission (g/test)		
				+15°F	+20°F	+24°F
CARB	3	9.0	60	0.71	1.05	1.45
			68	0.96	1.57	2.70
			75	1.82	3.54	6.54
		10.4	60	1.23	2.10	3.80
			68	1.72	4.29	9.05
			75	2.79	9.08	16.72
		11.8	60	2.12	4.24	8.14
			68	4.17	10.85	19.31
			75	9.99	24.14	42.38
FI	3	9.0	60	0.45	0.68	1.01
			68	0.41	0.80	1.61
			75	0.53	1.45	3.69
		10.4	60	0.61	1.33	2.65
			68	1.02	3.32	7.59
			75	1.70	7.00	16.35
		11.8	60	0.97	2.74	6.21
			68	2.03	8.09	17.99
			75	7.68	21.79	41.26

Table 2-19

UDI at ATL Diurnal Test Conditions*

RVP (psi)	Starting Temp. (°F)	UDI		
		+15°F	+20°F	+24°F
9.0	60	0.500	0.753	1.000
	68	0.706	1.072	1.438
	75	0.973	1.495	2.032
10.4	60	0.715	1.085	1.457
	68	1.034	1.595	2.175
	75	1.475	2.325	3.250
11.8	60	1.012	1.559	2.125
	68	1.521	2.403	3.372
	75	2.289	3.776	5.609

---

* Based on a 40% full tank.

Figure 2-10

ATL CARBURETED DIURNAL EMISSIONS

vs UDI

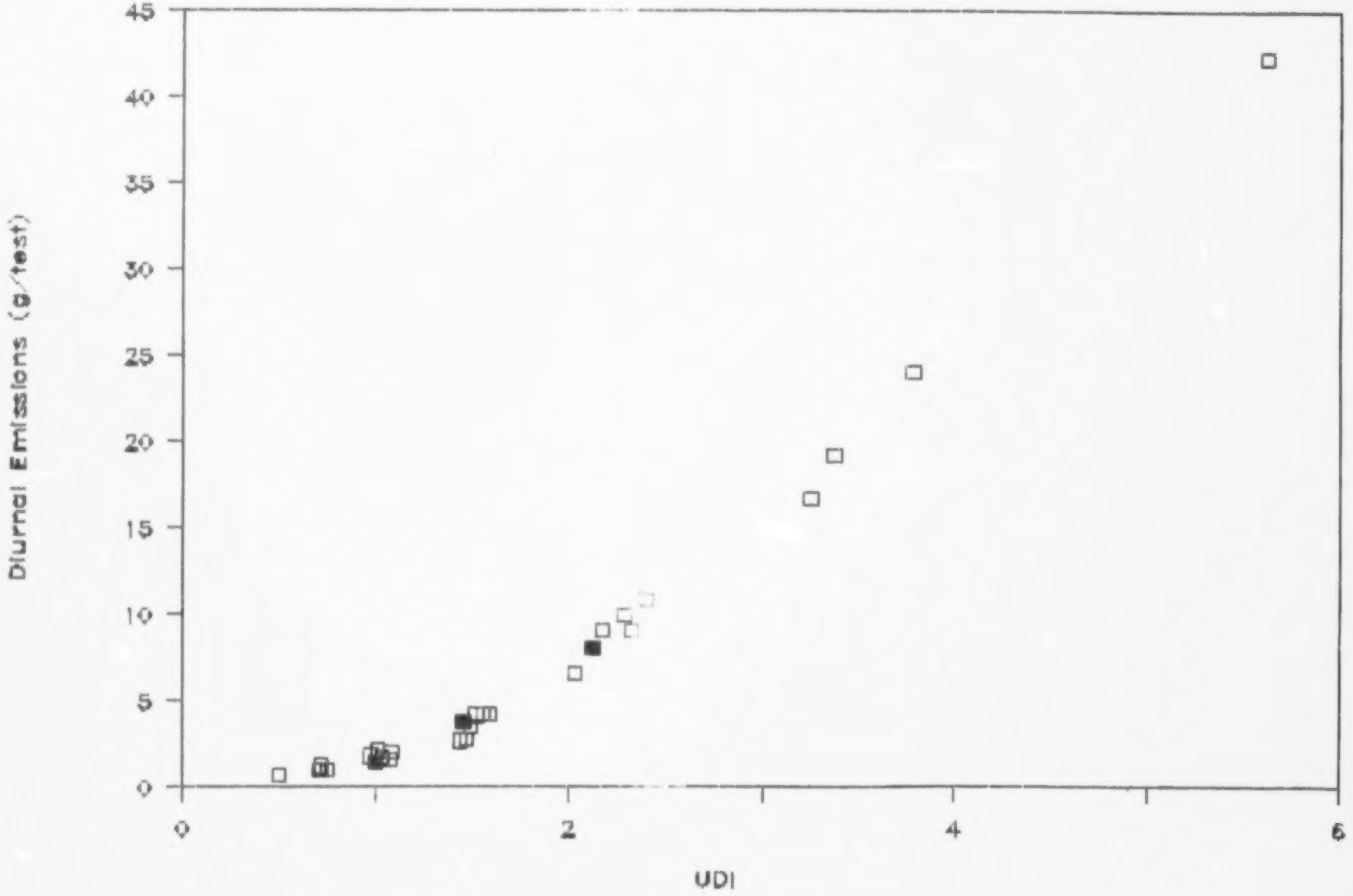
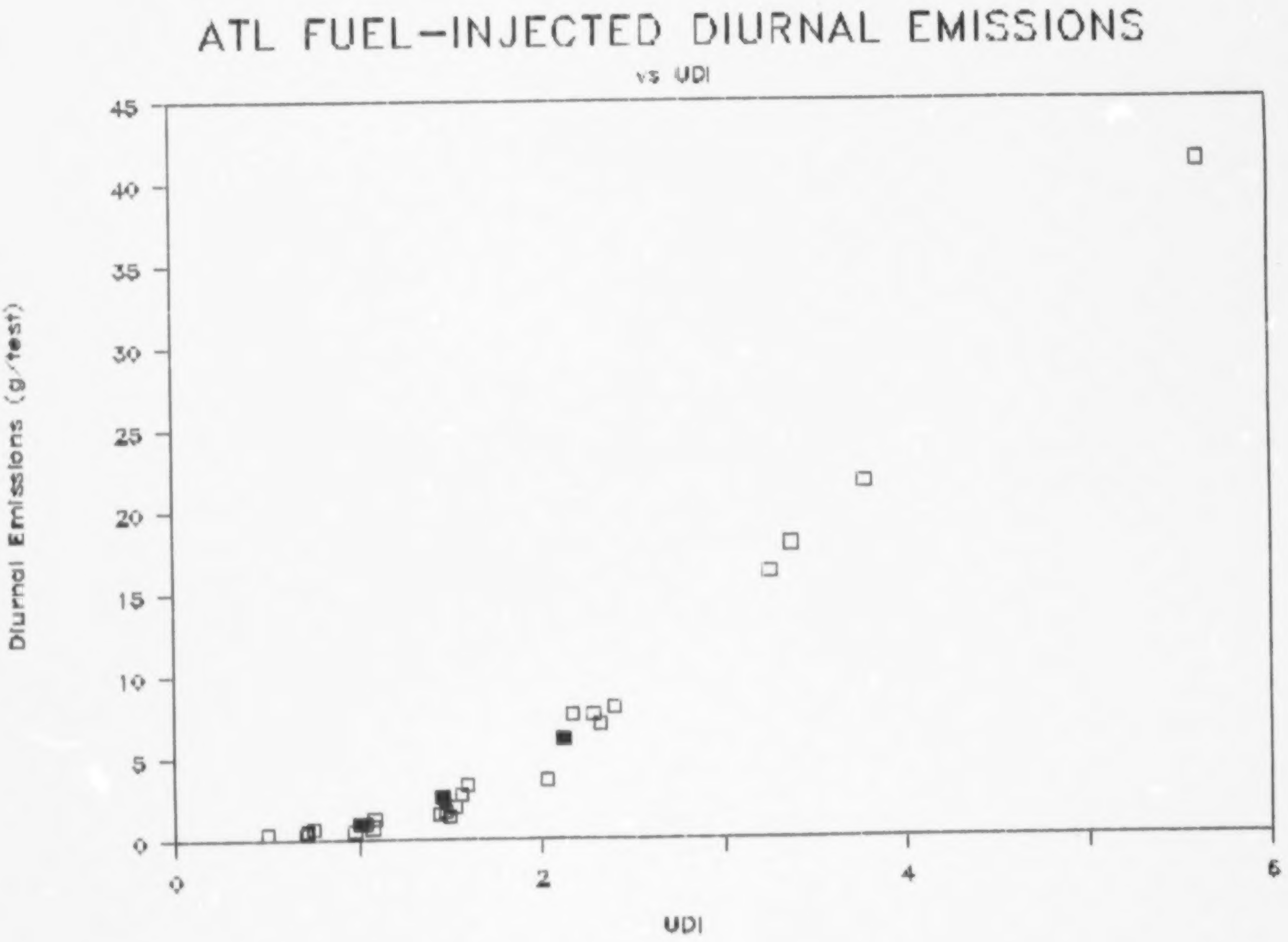


Figure 2-11


ATL FUEL-INJECTED DIURNAL EMISSIONS
vs UDI
Diurnal Emissions (g/test)
45
40
35
30
25
20
15
10
5
0
0
2
4
6
UDI

EPA in Ann Arbor performed evaporative emissions tests on vehicles with varying tank fill levels. Sixteen vehicles were tested over the FTP on commercial fuel at tank fill levels of 40, 20, 60, and 80 percent, in that order. The vehicle information and emissions are listed in Table 2-20. The diurnal and hot-soak emissions are presented graphically in Figures 2-12 and 2-13, respectively.

From the top half of Figure 2-12 for diurnal emissions, there is no clear trend in emissions versus fill level. However, as many test programs have shown, the order of testing a vehicle while varying a parameter (as for different RVPs) has a direct impact on the level of emissions. Testing the vehicles at a fill level out of order (i.e., testing at 40 percent full, first, then 20, 60 and 80 percent) appears to have had such an effect on diurnal emissions. When only the 20, 60, and 80 percent fill level diurnal emissions data is examined, the expected trend of a decrease in diurnal emissions with an increase in fill level can be seen clearer, as in the bottom half of Figure 2-12.

There appears to be no effect of fill level on hot-soak emissions as shown in Figure 2-13. No different trends exist when examining carbureted and fuel-injected vehicles separately.

ii. Hot-Soak Model

Uncontrolled hot-soak emissions originate from the carburetor or fuel-injection system, and the fuel tank to a degree due to recirculation of heated gas from the fuel pump. Uncontrolled hot-soak emissions are primarily a function of RVP, distillation characteristics, carburetor size, engine temperatures, and amount of recirculated gasoline. Unlike uncontrolled diurnal emissions, which are relatively straightforward to model, no reasonably accurate model was found or could be developed for uncontrolled hot-soak emissions. A similar approach to the diurnal model to calculate an uncontrolled hot-soak emission potential, based on the same ATL temperature data, engine temperature, and distillation properties of the fuel, and correlate it to controlled hot-soak emissions was attempted. Due to the lack of information on distillation properties, gasoline recirculation data, and reliable temperature effects data, the attempt was not successful. Therefore in-use hot-soak emissions are modeled as a function of in-use RVP, certification RVP, and ASTM limit RVP. The adjusted RVP level used in MOBILE3 to calculate in-use hot-soak emissions is as follows:

$$\text{Adjusted Hot-Soak RVP} = (\text{In-Use RVP}) \times \frac{11.5 \text{ psi}}{(\text{ASTM limit})} \times \frac{9.0 \text{ psi}}{(\text{Certification RVP})}$$

Table 2-20

Evaporative Emisions from Vehicles Tested at Varying Tank Fill Levels

Vehicle	Fuel Metering System	Diurnal Emissions (g/test) at Specified Tank Fill Levels				Hot-Soak Emissions (g/test) at Specified Tank Fill Levels			
		40%	20%	60%	80%	40%	20%	60%	80%
1984 Mercury Marquis	FI	0.27	0.20	0.28	0.54	0.32	0.39	0.35	0.23
1982 Pontiac J2000	FI	4.87	3.69	0.71	0.28	0.50	0.45	0.43	0.46
1982 Renault Fuego	FI	1.65	1.62	0.92	0.48	1.44	1.66	1.19	1.08
1982 Cadillac DeVille	FI	25.78	22.54	15.62	9.62	1.34	0.88	0.91	1.01
1985 Buick Century	FI	3.45	4.64	0.98	1.22	6.22	26.09	1.43	2.56
1983 Toyota Celica	FI	12.61	9.90	7.63	1.17	0.17	0.12	0.12	0.11
1982 Lincoln Mark VI	FI	15.29	7.75	11.19	9.93	1.09	0.74	0.94	0.43
1985 Chevrolet Cavalier	FI	1.29	5.28	0.90	0.49	0.33	1.06	0.51	0.42
1983 Ford Ranger	Carb	5.83	11.90	14.24	7.93	1.62	1.55	1.22	1.60
1982 Chrysler Diplomat	Carb	7.85	10.35	8.65	2.63	1.89	4.40	2.79	4.08
1982 Chevrolet Impala	Carb	22.67	38.13	16.69	9.55	5.66	5.05	5.19	5.31
1982 AMC Concord	Carb	19.89	12.68	13.62	6.50	1.10	1.30	1.76	1.21
1983 Chrysler Aries	Carb	7.44	12.13	5.73	2.19	1.01	1.22	1.24	1.09
1984 Chevy S-10	Carb	5.67	4.21	3.42	1.09	0.36	0.30	0.28	0.29
1985 Nissan Sentra	Carb	0.62	0.97	0.76	0.38	1.84	1.82	2.11	1.79
1985 Honda Civic	Carb	1.85	5.79	0.54	1.78	0.91	0.90	1.00	0.89

Figure 2-12

EVAPORATIVE DIURNAL EMISSIONS
AT VARYING TANK FILL LEVELS

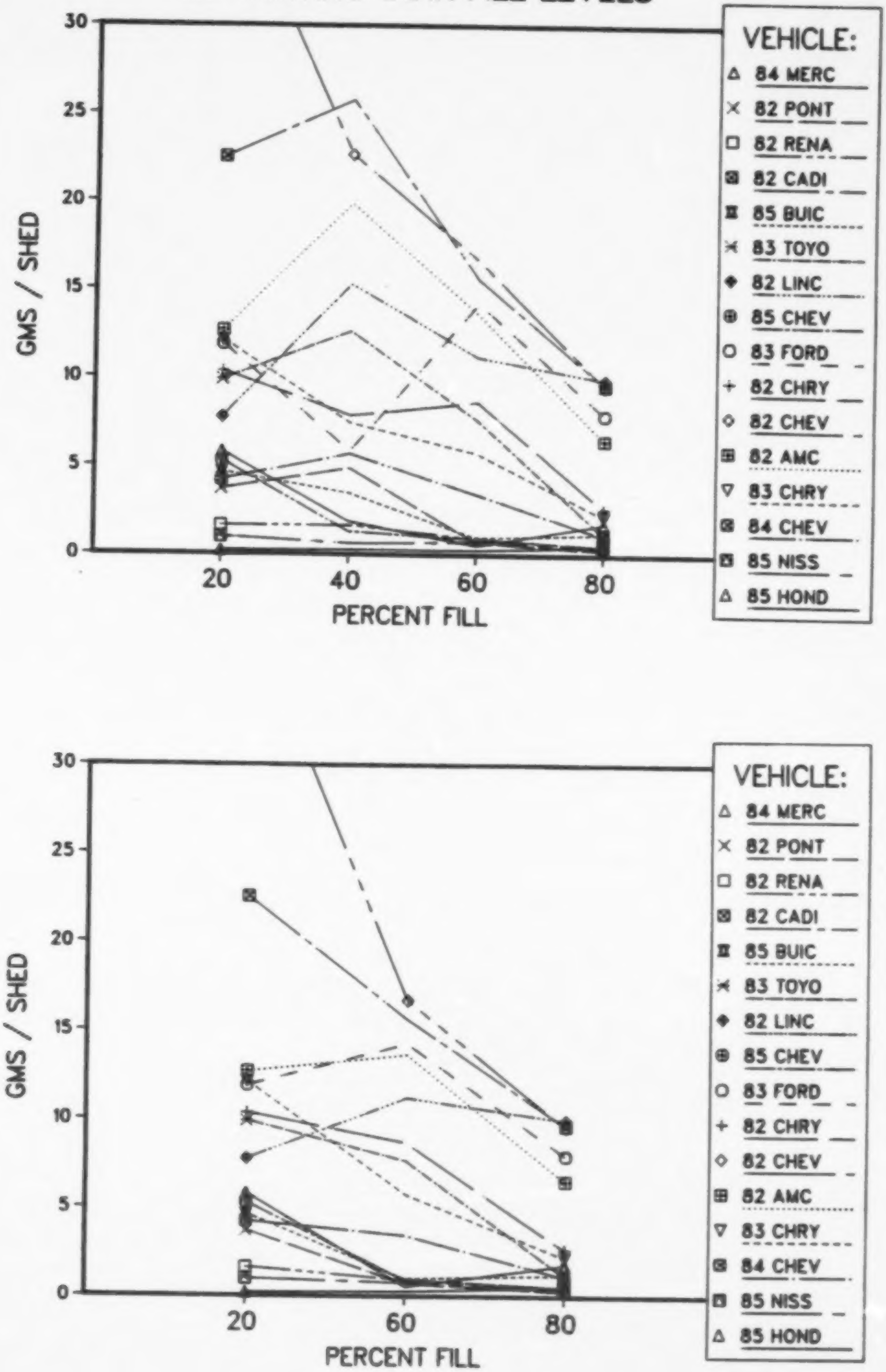
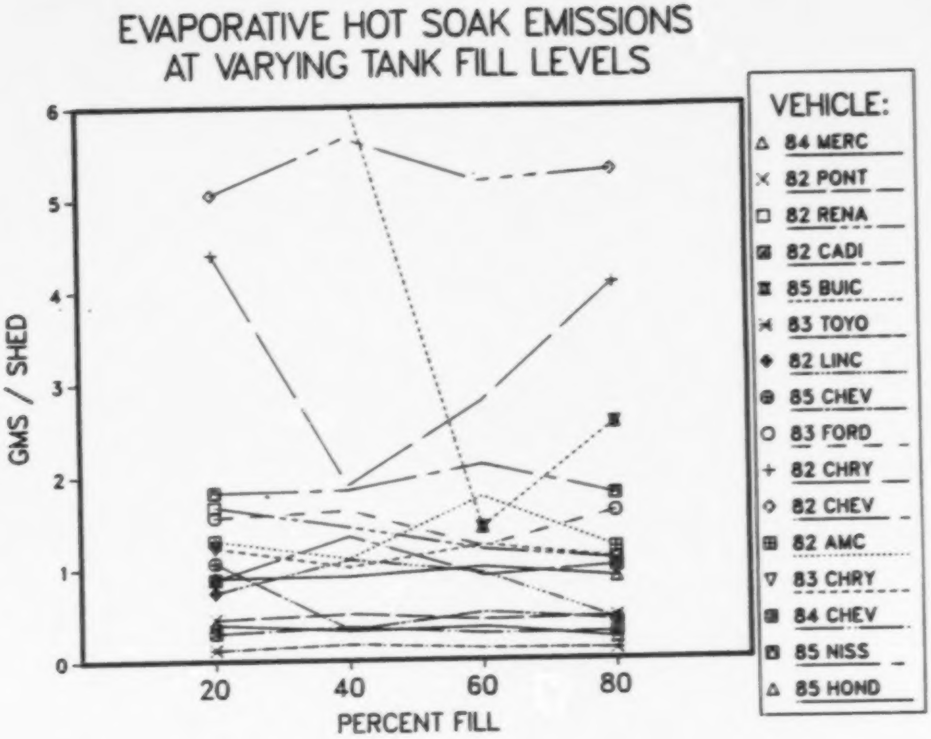


Figure 2-13


EVAPORATIVE HOT SOAK EMISSIONS
AT VARYING TANK FILL LEVELS
GMS / SHED
0
1
2
3
4
5
6
20
40
60
80
PERCENT FILL
VEHICLE:
△ 84 MERC
× 82 PONT
□ 82 RENA
▨ 82 CADI
⌶ 85 BUIC
⋈ 83 TOYO
◆ 82 LINC
⊖ 85 CHEV
○ 83 FORD
+ 82 CHRY
◇ 82 CHEV
⊞ 82 AMC
▽ 83 CHRY
▣ 84 CHEV
⊠ 85 NISS
△ 85 HOND

The ASTM limit term is an attempt to account for temperature differences between ASTM classes. The assumption is low RVPs and higher ambient temperatures typical of ASTM Classes A or B areas produce the same emissions potential as the high RVPs and lower ambient temperatures of ASTM Classes C, D or E areas. The certification RVP term accounts for the effect of a different certification RVP on emissions. The assumption is that a change in certification fuel RVP to a higher RVP level, would decrease controlled hot-soak emissions because a larger canister would be required to meet a 2-gram standard.

Similar attempts to verify the hot-soak model were not possible because of a lack of hot-soak models and reliable emissions data showing the effect of the relevant parameters on hot-soak emissions.

d. Fuel Weathering and Average In-Use Fuel Tank Level

As gasoline in vehicle fuel tank systems is heated by diurnal temperature increases, many of the more volatile hydrocarbons in the gasoline mixture are lost, thus decreasing the volatility of the fuel. This phenomenon, known as weathering, is an important consideration in assessing evaporative emissions that actually occur in the field. This section will describe how the diurnal evaporative emissions model was adjusted to account for the effects of fuel weathering and in-use tank fill level.

During the summer of 1985, EPA conducted a study which examined the effects of weathering on the RVP of gasoline as the vehicle's fuel tank is emptied by use.[35] Three carbureted test vehicles fueled with commercial fuel were driven for three trips per day (one 12 mile trip and two 8 mile trips) on Mondays through Thursdays, and were parked outside on weekends. Results of this testing showed that fuel RVP can drop by as much as 0.9 psi by the time a vehicles fuel tank goes from full to 40 percent full. Test results also show that the RVP of the fuel drops faster as the fuel tank level decreases. This is to be expected, since diurnal evaporative emissions are higher due to greater vapor space and since the lesser amounts of liquid fuel are heated to higher temperatures during vehicle operation, driving off more of the lighter hydrocarbons.

Another factor, related to weathering, which must be incorporated into estimations of evaporative emissions is the variations in in-use fuel tank levels. Since the amount of uncontrolled diurnal emissions is directly proportional to the amount of vapor space in the fuel tank (Wade's equation for uncontrolled diurnal emissions), a fuel tank that is 20 percent full will produce greater emissions than the same size fuel tank at 80 percent full, all other conditions being equal.

However, since emissions also decrease with decreasing fuel RVP the emissions of a 20 percent full tank in which the fuel has weathered significantly may be less than those of an 80 percent full tank with unweathered fuel.

Hence we see that in order to model vehicle emissions, we need to know present tank level, the dispensed fuel RVP, and the amount of weathering that has been experienced. Further complicating matters is the problem of determining the amount of RVP loss experienced during the refueling of the vehicle and accounting for the mixing of low RVP fuel already in the tank before refueling with the dispensed fuel. As both fuel usage and weathering occur in concert their effects on emissions are best dealt with analytically together.

In order to model evaporative emissions while incorporating weathering and fuel tank level effects, ideally one would conduct a survey of vehicles in the private sector and measure tank RVP, fuel tank level, and local dispensed RVP levels. From this distribution of vehicle and fuel volatility situations one could develop a reasonably accurate model of fleet emissions.

Since a survey of this nature was not available for use, distributions of vehicle fuel tank situations based on four refueling surveys and weathering estimates from the above mentioned EPA weathering study were generated. Though this limited amount of refueling data could be influenced by uncontrolled parameters (i.e., gas prices, credit card usage, fuel station location, self-serve vs. full-serve orientation, etc.), no other reliable refueling data was available for use at this time.

Three of the four refueling surveys used in this analysis were part of an efficiency evaluation survey of Stage II refueling vapor recovery systems. Two of these surveys were performed by Scott Environmental Technology, Inc.; the other by Exxon Research and Engineering Co. From the three surveys, the results of only those vehicles on which fuel tank size information could be found were used. The survey performed by Exxon was conducted in April of 1976 at a service station in Linden, New Jersey.[36] Two hundred seventy six of the refueling events (attendant serve) contained in this survey were used, 181 of which (66 percent) were complete fillups. The second survey, prepared for CARB by Scott Environmental Technology Inc., was conducted in 1979 at a Union 76 Service Station, out of which 81 attendant serve refueling events were used, 74 of which (91 percent) were fillups.[37] The third survey was performed by Scott Environmental Technology, Inc., for Cambridge Engineering, Inc. in 1981 at a World Oil Company service station in Los Angeles, from which 94 self serve refueling events were used, 18 of which (19 percent) were fillups.[38]

Each of these three surveys contained information on vehicle type, amount of fuel dispensed, and whether or not each vehicle was filled completely. These three surveys were somewhat incomplete however, in that the fuel tank level of the vehicles before refueling was not measured. The fourth survey, conducted by GM, did have information on fuel tank levels before refueling, and was therefore used as the preferential database, as will be discussed below . By using the combined data from the three incomplete surveys, and vehicle tank sizes from the Automotive News Market Data Book Issue, a distribution of complete and partial fills was generated showing fill fractions and the number (and fraction) of vehicles in each particular situation, as presented in Table 2-21.

The contents of Table 2-21 show a "snapshot" distribution of vehicle refueling events at the service stations. In order to model emissions, however, one needs a "snapshot" distribution of the refueling characteristics of all vehicles in society. These are not the same. For instance, assuming all vehicles consume the same fraction of their fuel tank capacity each day, a vehicle which refuels from empty to 50 percent full will need to refuel twice as often as a vehicle which refuels from empty to 100 percent full. Therefore, if an equal number of 50 percent fillers and 100 percent fillers existed in society, a service station refueling survey would show twice as many 50 percent refueling events as 100 percent refueling events. Similarly, one would observe four times as many 25 percent refueling events. In order to account for the higher frequency of appearance of those who refuel in small amounts, the number of vehicles at each percent of tank filled range was multiplied (see Table 2-21) by the average fuel tank fill fraction to obtain a weighted number of vehicles in each refueling situation. The results of this computation are given in Table 2-22.

Since no measurements were taken of the vehicle fuel tank levels before and after partial fills, it was necessary to determine them analytically from the amount of fuel dispensed. The weighted number of vehicles in each partial fill category (see Table 2-22) were divided equally among likely combinations of initial and final tank levels, under the following three assumptions: 1) vehicle fill levels were divided to the nearest 10 percent, 2) no vehicles were 0 percent full before refueling, and 3) none of the vehicles were greater than 40 percent full before refueling, since Table 2-22 shows that very few weighted, in-use vehicles undergoing complete fillups were greater than 40 percent full before refueling. The resulting distribution for partial fills is shown in Table 2-23. For

Table 2-21

Results of the Three Incomplete Refueling Surveys

Complete Fillups

% Full Before Refueling	Amount Dispensed (% of Tank)	E*	S** Carb	S*** CAM	Total # Vehicles	% of Vehicles
70 (65-75)	30 (25-35)	2	3	0	5	1.11
60 (55-65)	40 (35-45)	18	6	1	25	5.54
50 (45-55)	50 (45-55)	28	6	1	35	7.76
40 (35-45)	60 (55-65)	32	19	0	51	11.31
30 (25-35)	70 (65-75)	31	14	6	51	11.31
20 (15-25)	80 (75-85)	41	17	5	63	13.97
10 (5-15)	90 (85-95)	29	9	5	43	9.53
		181	74	18	273	60.53

Partial Fills

Amount Dispensed (% of Tank)	E*	S** Carb	S*** Cam	Total # Vehicles	% of Vehicles
90 (85-95)	0	0	0	0	0.00
80 (75-85)	1	0	1	2	0.44
70 (65-75)	6	0	10	16	3.55
60 (55-65)	10	0	10	20	4.43
50 (45-55)	16	3	19	38	8.43
40 (35-45)	32	1	19	52	11.53
30 (25-35)	17	1	11	29	6.43
20 (15-25)	11	2	6	19	4.21
10 (5-15)	2	0	0	2	0.44
	95	7	76	178	39.46

* E =Exxon Survey
(# Vehicles)

** S =Scott Envr. Tech.
Carb Survey (for CARB)
(# Vehicles)

*** S =Scott Envr. Tech.
Cam Survey (for Cambridge)
(# Vehicles)

Table 2-22

Determination of a Distribution of In-Use Refueling Patterns from Service Station Refueling Patterns
(Three Incomplete Surveys)

Complete Fillups

% Full Before Refueling	# Vehicles (Srv. Station)	% Vehicles (Srv. Station)	# of Vehicles (In-use)	% of Vehicles (In-use)
70 (65-75)	5	1.11	1.5	0.57
60 (55-65)	25	5.54	10.0	3.82
50 (45-55)	35	7.76	17.5	6.69
40 (35-45)	51	11.31	30.6	11.69
30 (25-35)	51	11.31	35.7	13.64
20 (15-25)	63	13.97	50.4	19.26
10 (5-15)	43	9.53	38.7	14.79
	273	60.53	184.4	70.46

Partial Fills

Amount Dispensed (% of Tank)	# Vehicles (Srv. Station)	% Vehicles (Srv. Station)	# of Vehicles (In-use)	% of Vehicles (In-use)
90 (85-95)	0	0.00	0.0	0.00
80 (75-85)	2	0.44	1.6	0.61
70 (65-75)	16	3.55	11.2	4.28
60 (55-65)	20	4.43	12.0	4.59
50 (45-55)	38	8.43	19.0	7.26
40 (35-45)	52	11.53	20.8	7.95
30 (25-35)	29	6.43	8.7	3.32
20 (15-25)	19	4.21	3.8	1.45
10 (5-15)	2	0.44	0.2	0.08
	178	39.46	77.30	29.54

Table 2-23

Determination of Initial and Final Tank Levels for Partial Fills (Three Incomplete Surveys)

Partial Fills

Amount Dispensed (% of Tank)	# of Vehicles (In-use)	Tank Level After Refueling (% Full)	Tank Level Before Refueling (% Full)	# of Vehicles (In-use)
80	1.6	90	10	1.60
70	11.2	90	20	5.60
		80	10	5.60
60	12.0	90	30	4.00
		80	20	4.00
		70	10	4.00
50	19.0	90	40	4.75
		80	30	4.75
		70	20	4.75
		60	10	4.75
40	20.8	80	40	5.20
		70	30	5.20
		60	20	5.20
		50	10	5.20
30	8.7	70	40	2.18
		60	30	2.18
		50	20	2.18
		40	10	2.18
20	3.8	60	40	0.95
		50	30	0.95
		40	20	0.95
		30	10	0.95
10	0.2	50	40	0.05
		40	30	0.05
		30	20	0.05
		20	10	0.05

instance, the 11.2 vehicles that were filled 70 percent of capacity, were divided equally (5.6 vehicles each) between vehicles being filled from 20 percent full initially to 90 percent full and from ten percent full initially to 80 percent full. This process was repeated for each of the partial fill amounts shown in Table 2-22.

In order to model fleet emissions, it was necessary to make an estimate of the vehicle fuel consumption rate. All of the vehicles from the surveys were normalized to a fuel tank size of 16 gallons (the sales-weighted average of 1984 automobiles). Using the MOBILE3 Fuel Consumption Model estimates for 1988, it was determined that light-duty gasoline vehicles consume 1.24 gallons per day, or about eight percent of a 16 gallon tank. For simplicity's sake, and since the amount of weathering was determined in terms of tank percent full instead of time anyway, we assumed that fuel consumption occurred at roughly ten percent of tank per day.

Vehicles were assumed to have consumed this ten percent of their tank before experiencing their diurnal each day, thus, vehicle tanks were assumed to never have experienced diurnals at their fullest level. Rather vehicles ranging from 100 percent full to 70 percent full, for instance, would experience one-third of their diurnals at 90 percent, one-third at 80 percent, and one-third at 70 percent full, but none at 100 percent full. Calculations were done in this way because it was assumed that all cars would experience some amount of driving between refueling and the first diurnal. It also partially offsets the previous assumption that no cars run down below ten percent full prior to refueling. Using these assumptions, a distribution of vehicle situations showing percent full after refueling and present percent full was generated and is shown in Table 2-24.

Recently, the results of a gas and service station survey conducted in the Detroit area by General Motors Corporation became available for use.[39] The survey contained information on fuel tank levels both before and after refueling for 1,184 customers, 60.6 percent of which filled their vehicles completely. The results of the survey were then categorized in the same way as were the other three refueling surveys, and are presented in Table 2-25. One advantage of the GM data over the results of the other three surveys is the fact that the initial tank levels were recorded for all partial fills, which eliminates some of the uncertainty inherent in the other three surveys' results. Since the GM survey did report the initial tank levels and also because the data was much more recent than the other surveys (1986 as opposed to late 1970's and early 1980's), the GM survey results were evaulated independently of the results of the other three surveys. Another reason why the

Table 2-24

Distribution of Vehicle Situations

Tank Level After Refuel <Percent Full>	Present Tank Level <Percent Full>	Percentage of Vehicles <Three Incomplete Surveys>
100	100	0.000
100	90	10.432
100	80	10.432
100	70	10.432
100	60	10.241
100	50	9.285
100	40	7.948
100	30	5.999
100	20	4.050
100	10	1.643
100	0	0.000
90	90	0.000
90	80	1.000
90	70	1.000
90	60	1.000
90	50	1.000
90	40	1.000
90	30	0.637
90	20	0.382
90	10	0.076
90	0	0.000
80	80	0.000
80	70	1.420
80	60	1.420
80	50	1.420
80	40	1.420
80	30	0.923
80	20	0.560
80	10	0.306
80	0	0.000
70	70	0.000
70	60	1.392
70	50	1.392
70	40	1.392
70	30	1.115
70	20	0.618
70	10	0.255
70	0	0.000
60	60	0.000
60	50	1.319
60	40	1.319
60	30	1.137
60	20	0.860
60	10	0.363
60	0	0.000
50	50	0.000
50	40	0.975
50	30	0.956
50	20	0.774
50	10	0.497
50	0	0.000
40	40	0.000
40	30	0.478
40	20	0.459
40	10	0.278
40	0	0.000
30	30	0.000
30	20	0.201
30	10	0.182
30	0	0.000
20	20	0.000
20	10	0.019
20	0	0.000
10	10	0.000
10	0	0.000

Table 2-25

Results of GM Refueling Survey

Tank Level After Refueling [Percent Full]	Tank Level Before Refueling [Percent Full]	Number of Vehicles in Survey	Percentage of Tank Filled	Weighted Number of Vehicles
100 (>95)	0 (<5)	68	100	68.0
100 (>95)	10 (5-14)	239	90	215.1
100 (>95)	20 (15-24)	68	80	54.4
100 (>95)	30 (25-34)	199	70	139.3
100 (>95)	40 (35-44)	49	60	29.4
100 (>95)	50 (45-54)	68	50	34.0
100 (>95)	60 (55-64)	7	40	2.8
100 (>95)	70 (65-74)	8	30	2.4
100 (>95)	80 (75-84)	12	20	2.4
100 (>95)	90 (85-94)	2	10	0.2
100 (>95)	100 (>94)	0	0	0.0
90 (86-95)	0 (<5)	6	90	5.4
90 (86-95)	10 (5-14)	28	80	22.4
90 (86-95)	20 (15-24)	7	70	4.9
90 (86-95)	30 (25-34)	21	60	12.6
90 (86-95)	40 (35-44)	2	50	1.0
90 (86-95)	50 (45-54)	3	40	1.2
90 (86-95)	60 (55-64)	0	30	0.0
90 (86-95)	70 (65-74)	0	20	0.0
90 (86-95)	80 (75-84)	0	10	0.0
90 (86-95)	90 (85-94)	0	0	0.0
80 (76-85)	0 (<5)	4	80	3.2
80 (76-85)	10 (5-14)	22	70	15.4
80 (76-85)	20 (15-24)	5	60	3.0
80 (76-85)	30 (25-34)	8	50	4.0
80 (76-85)	40 (35-44)	3	40	1.2
80 (76-85)	50 (45-54)	1	30	0.3
80 (76-85)	60 (55-64)	1	20	0.2
80 (76-85)	70 (65-74)	0	10	0.0
80 (76-95)	80 (75-84)	0	0	0.0
70 (66-75)	0 (<5)	11	70	7.7
70 (66-75)	10 (5-14)	28	60	16.8
70 (66-75)	20 (15-24)	7	50	3.5
70 (66-75)	30 (25-34)	26	40	10.4
70 (66-75)	40 (35-44)	3	30	0.9
70 (66-75)	50 (45-54)	1	20	0.2
70 (66-75)	60 (55-64)	0	10	0.0
70 (66-75)	70 (65-74)	0	0	0.0
60 (56-65)	0 (<5)	7	60	4.2
60 (56-65)	10 (5-14)	17	50	8.5
60 (56-65)	20 (15-24)	3	40	1.2
60 (56-65)	30 (25-34)	10	30	3.0
60 (56-65)	40 (35-44)	1	20	0.2
60 (55-65)	50 (45-54)	0	10	0.0
60 (56-65)	60 (55-64)	0	0	0.0
50 (46-55)	0 (<5)	11	50	5.5
50 (46-55)	10 (5-14)	49	40	19.6
50 (46-55)	20 (15-24)	11	30	3.3
50 (46-55)	30 (25-34)	18	20	3.6
50 (46-55)	40 (35-44)	0	10	0.0
50 (46-55)	50 (45-54)	0	0	0.0
40 (36-45)	0 (<5)	15	40	6.0
40 (36-45)	10 (5-14)	32	30	9.6
40 (36-45)	20 (15-24)	5	20	1.0
40 (36-45)	30 (25-34)	11	10	1.1
40 (36-45)	40 (35-44)	0	0	0.0
30 (26-35)	0 (<5)	11	30	3.3
30 (26-35)	10 (5-14)	21	20	4.2
30 (26-35)	20 (15-24)	2	10	0.2
30 (26-35)	30 (25-34)	0	0	0.0
20 (16-25)	0 (<5)	18	20	3.6
20 (16-25)	10 (5-14)	24	10	2.4
20 (16-25)	20 (15-24)	1	0	0.0
10 (6-15)	0 (<5)	8	10	0.8
10 (6-15)	10 (5-14)	1	0	0.0
0 (<6)	0 (<5)	1	0	0.0

results of this survey were not evaluated together with the results of the other three surveys was because a number of the vehicles reported a completely empty tank before refueling in the GM survey, whereas the lowest tank level assumed in the three incomplete surveys was ten percent full.

For these reasons, two additional distributions of vehicle situations (as in Table 2-24) were then generated from the GM refueling survey results. One distribution was generated assuming that ten percent of the fuel in the tank was consumed before the first diurnal (a "worst-case" scenario), while the other was generated assuming that ten percent of the fuel in the tank was consumed after the first diurnal (a "best case" scenario). Both distributions are shown in Table 2-26.

In order to account for the effect of weathering in the model, weathering data was taken from the results of the study performed by EPA during the summer of 1985 in which three carbureted vehicles underwent two weeks of outdoor testing. The three vehicles were initially filled with commercial grade fuel after which the RVP of the fuel in the tank was measured. The vehicles were then driven three trips per day (one 12 mile trip in the morning and two 8 mile trips in the afternoon) on Mondays through Thursdays, and parked outside Fridays through Sundays. Figure 2-14 shows the RVP drop of the three test vehicles as a function of fuel tank level.

Although weathering studies which showed results similar to our own were available from General Motors Corporation and Southwest Research Institute, they were not used in this analysis.[40,41] The General Motors study was not used primarily because of the unrepresentatively high fuel tank temperatures (110-120°F) which occurred during testing (the vehicles were operated on a dynamometer with relatively short time intervals between driving cycles of about one hour), which would tend to increase the amount of weathering experienced. The study by Southwest Research was not used because the vehicles tested underwent unusually long cycles (50 mile trips daily) and because the vehicles were parked in a controlled environment (76° F) on days when they were not driven.

To estimate weathering in our model, we used the average RVP drop of the three EPA test vehicles between two given tank levels using Figure 2-14. These values are shown for the EPA test results, as well as for the GM and SWRI results in Table 2-27. For instance, the amount of weathering between 50 percent full and 40 percent full is 0.17 psi. The weathering was always assumed to be the same between given fuel tank levels, regardless of the initial tank RVP or the initial fill level. This assumption is based on the results of the Vehicle Tank Fuel Weathering test program by General Motors

Table 2-26

Distribution of Vehicle Situations

Tank Level After Refuel (Percent Full)	Present Tank Level (Percent Full)	Percentage of Vehicles (OM Refueling Survey--10% of Tank Consumed Before 1st Diurnal)	Percentage of Vehicles (OM Refueling Survey--No Fuel Consumed Before 1st Diurnal)
100	100	0.000	9.683
100	90	9.683	9.656
100	80	9.656	9.494
100	70	9.494	9.387
100	60	9.387	9.293
100	50	9.293	8.378
100	40	8.378	7.719
100	30	7.719	5.043
100	20	5.043	4.129
100	10	4.129	0.914
100	0	0.914	0.000
90	90	0.000	0.901
90	80	0.901	0.901
90	70	0.901	0.901
90	60	0.901	0.901
90	50	0.901	0.861
90	40	0.861	0.834
90	30	0.834	0.551
90	20	0.551	0.457
90	10	0.457	0.081
90	0	0.081	0.000
80	80	0.000	0.592
80	70	0.592	0.592
80	60	0.592	0.578
80	50	0.578	0.565
80	40	0.565	0.524
80	30	0.524	0.417
80	20	0.417	0.350
80	10	0.350	0.054
80	0	0.054	0.000
70	70	0.000	1.022
70	60	1.022	1.022
70	50	1.022	1.009
70	40	1.009	0.968
70	30	0.968	0.619
70	20	0.619	0.524
70	10	0.524	0.148
70	0	0.148	0.000
60	60	0.000	0.511
60	50	0.511	0.511
60	40	0.511	0.498
60	30	0.498	0.363
60	20	0.363	0.323
60	10	0.323	0.094
60	0	0.094	0.000
50	50	0.000	1.197
50	40	1.197	1.197
50	30	1.197	0.955
50	20	0.955	0.807
50	10	0.807	0.148
50	0	0.148	0.000
40	40	0.000	0.847
40	30	0.847	0.699
40	20	0.699	0.632
40	10	0.632	0.202
40	0	0.202	0.000
30	30	0.000	0.457
30	20	0.457	0.430
30	10	0.430	0.148
30	0	0.148	0.000
20	20	0.000	0.565
20	10	0.565	0.242
20	0	0.242	0.000
10	10	0.000	0.108
10	0	0.108	0.000

FIGURE 2-14 RVP DROP as a function of TANK LEVEL (EPA WEATHERING DATA)

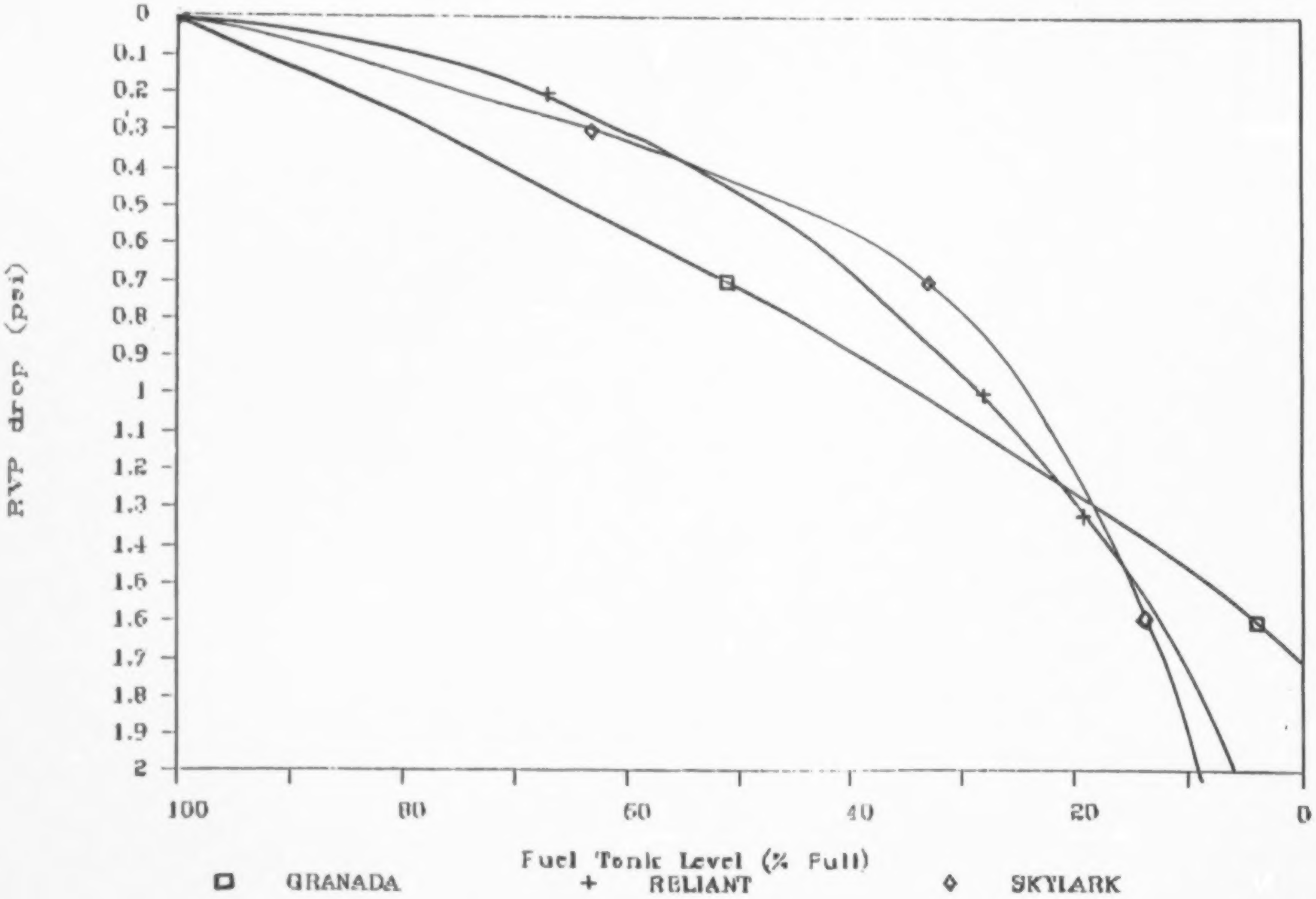


Table 2-27

RVP Drop as a Function of Tank Level

Initial Fill Level (% Full)	Final Fill Level (% Full)	EPA Data RVP Drop	GM Data RVP Drop	SWRI Data RVP Drop
100	90	.07	.31	.13
90	80	.09	.19	.13
80	70	.10	.16	.04
70	60	.13	.17	.05
60	50	.14	.18	.07
50	40	.17	.28	.06
40	30	.22	.34	.08
30	20	.30	.33	.10
20	10	.44	.29	.17
10	0	.50	---	---

Corporation.[39] This study observed the amount of weathering experienced by four fuel injected vehicles driven approximately 30 miles per day in the Environmental Test Chamber at the General Motors Proving Ground. Two test fuels were used one with RVP of 11.8 psi and the other with RVP of 10.4. It was found that the average amount of weathering experienced from the as-dispensed level to the 40 percent level was 1.08 psi RVP for the 11.8 RVP fuel and 1.41 psi for the 10.4 RVP fuel. Although an opposite relationship would be expected (i.e., the more volatile fuel should weather more), the results for these two fuels seem to support the simplifying assumption with respect to weathering and fill tank level used in our model.

Once the distribution of vehicle situations and the amounts of weathering were determined, uncontrolled diurnal emissions were calculated for various cities using the uncontrolled diurnal emissions equation presented earlier in this chapter. Calculations were performed using 30-year average high and low July temperatures which were taken from the "Statistical Abstract of the United States, National Data Book and Guide to Sources," and using ozone non-attainment design value day temperatures.[42] Dispensed fuel RVP was assumed to be at the ASTM limit for each city. All calculations were done assuming a 16 gallon tank with 2 gallon head space, and assuming that the vapor space volume remained constant during each diurnal.

Next, to estimate controlled emissions, the UDI was calculated for each vehicle situation. As explained earlier, this is defined as the ratio of uncontrolled emissions at the given conditions to the uncontrolled emissions for the same size fuel tank at certification test conditions (i.e., 40 percent full tank, 9.0 RVP fuel, 60°F to 84°F temperature rise). The UDI has been correlated with non-tampered controlled emissions for a number of vehicles, yielding the following equations:

1) Controlled Diurnal Emissions = $1.8283 \times (\text{UDI})^2$
(fuel-injected vehicles)

2) Controlled Diurnal Emissions = $2.2777 \times (\text{UDI})^2$
(carbureted vehicles)

These equations were determined by curve-fitting the EF test data versus the UDI. This is a simpler form of the equations derived in Appendix 2-A, however, this should have minimal effect on the adjusted fuel tank level which is back-calculated from these equations as explained in the following paragraphs.

Assuming that about about 88 percent of all vehicles are fuel-injected, while 12 percent are carbureted*, these equations can be combined to give:

3) Controlled Diurnal Emissions = $1.8822 \times (\text{UDI})^2$
(all vehicles)

Sample calculations of controlled diurnal emissions for each vehicle situation (as per the three incomplete refueling surveys) using the ASTM fuel RVP and average July temperatures for the city of Detroit are shown in Table 2-28. Average fleet controlled emissions were calculated by multiplying the controlled diurnal emissions for each vehicle situation with the appropriate weighting factors (from Tables 2-24 and 2-26).

The average controlled emission value was then used to back calculate average uncontrolled emissions using the UDI correlation (eqn. 3). The uncontrolled diurnal emission equation was then used along with city specific average July temperatures (or ozone design value day temperatures) and dispensed fuel RVP, to give an effective average vapor space volume, which was converted to a fuel tank level. This effective average fuel tank level can be used to incorporate the effects of weathering and variations in fuel tank levels into calculations of average fleet emissions for each city using city specific temperatures and dispensed fuel RVP. Results of the calculations of the effective fuel tank level for nine of the ten largest non-California urban areas** are shown in Table 2-29.

Instead of finding a large variance between cities in this representative fuel tank level, it was found that a fuel tank level of approximately 60 percent full was fairly well representative for each city modeled. The representative fuel tank levels for each city were then population weighted and averaged. Using ozone design value day temperatures and the GM refueling survey data, it appears that the representative fuel tank level lies somewhere between 61.01 and 64.70 percent full

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* The accuracy of this assumption is not critical, since the results of the model are determined by taking the ratio of controlled emissions at different situations. Hence the value of the constant in eqn. 3 is not important, since it drops out of the calculations.

** Calculations were not performed for Miami since ozone design temperatures for this city were taken from a winter day with a small diurnal temperature rise. All other ozone design temperatures occurred during the summer months.

Table 2-28

Diurnal Emissions for the Distribution of In-Use Vehicle Situations
(Calculations Performed Using Detroit Average July Temperatures and ASTM Fuel RVP)

Tank Level After Refuel [% Full]	Present Tank Level [% Full]	Present RVP	UDI	Controlled Emissions [grams]	Weighting Factor (3 Incomplete Surveys Combined)	Weighted Emissions
100	100	11.50	0.299	0.17	0.0000	0.000
100	90	11.43	0.526	0.52	0.1043	0.054
100	80	11.34	0.741	1.03	0.1043	0.108
100	70	11.24	0.940	1.66	0.1043	0.174
100	60	11.11	1.118	2.35	0.1024	0.241
100	50	10.97	1.277	3.07	0.0929	0.285
100	40	10.80	1.410	3.74	0.0795	0.297
100	30	10.58	1.505	4.26	0.0600	0.256
100	20	10.28	1.547	4.50	0.0405	0.182
100	10	9.84	1.511	4.29	0.0164	0.071
100	0	9.34	1.438	3.89	0.0000	0.000
90	90	11.50	0.537	0.54	0.0000	0.000
90	80	11.41	0.756	1.08	0.0100	0.011
90	70	11.31	0.960	1.73	0.0100	0.017
90	60	11.18	1.141	2.45	0.0100	0.025
90	50	11.04	1.304	3.20	0.0100	0.032
90	40	10.87	1.439	3.90	0.0100	0.039
90	30	10.65	1.536	4.44	0.0064	0.028
90	20	10.35	1.578	4.69	0.0038	0.018
90	10	9.91	1.541	4.47	0.0008	0.003
90	0	9.41	1.467	4.05	0.0000	0.000
80	80	11.50	0.776	1.13	0.0000	0.000
80	70	11.40	0.986	1.83	0.0142	0.026
80	60	11.27	1.172	2.58	0.0142	0.037
80	50	11.13	1.339	3.37	0.0142	0.048
80	40	10.96	1.477	4.11	0.0142	0.058
80	30	10.74	1.576	4.68	0.0092	0.043
80	20	10.44	1.620	4.94	0.0056	0.028
80	10	10.00	1.581	4.71	0.0031	0.014
80	0	9.50	1.505	4.26	0.0000	0.000
70	70	11.50	1.015	1.94	0.0000	0.000
70	60	11.37	1.207	2.74	0.0139	0.038
70	50	11.23	1.379	3.58	0.0139	0.050
70	40	11.06	1.521	4.36	0.0139	0.061
70	30	10.84	1.623	4.96	0.0112	0.055
70	20	10.54	1.668	5.23	0.0062	0.032
70	10	10.10	1.627	4.99	0.0026	0.013
70	0	9.60	1.548	4.51	0.0000	0.000
60	60	11.50	1.254	2.96	0.0000	0.000
60	50	11.36	1.433	3.86	0.0132	0.051
60	40	11.19	1.581	4.70	0.0132	0.062
60	30	10.97	1.686	5.35	0.0114	0.061
60	20	10.67	1.732	5.65	0.0086	0.049
60	10	10.23	1.689	5.37	0.0036	0.020
60	0	9.73	1.607	4.86	0.0000	0.000
50	50	11.50	1.493	4.20	0.0000	0.000
50	40	11.33	1.647	5.11	0.0098	0.050
50	30	11.11	1.757	5.81	0.0096	0.056
50	20	10.81	1.804	6.13	0.0077	0.047
50	10	10.37	1.759	5.82	0.0050	0.029
50	0	9.87	1.672	5.26	0.0000	0.000
40	40	11.50	1.732	5.64	0.0000	0.000
40	30	11.28	1.847	6.42	0.0048	0.031
40	20	10.98	1.896	6.77	0.0046	0.031
40	10	10.54	1.848	6.43	0.0028	0.018
40	0	10.04	1.756	5.80	0.0000	0.000
30	30	11.50	1.971	7.31	0.0000	0.000
30	20	11.20	2.023	7.70	0.0020	0.015
30	10	10.76	1.970	7.31	0.0018	0.013
30	0	10.26	1.870	6.58	0.0000	0.000
20	20	11.50	2.210	9.19	0.0000	0.000
20	10	11.06	2.151	8.71	0.0002	0.002
20	0	10.56	2.040	7.83	0.0000	0.000
10	10	11.50	2.448	11.28	0.0000	0.000
10	0	11.00	2.319	10.13	0.0000	0.000
					Weighted Average	---------
					Fleet Emissions =	2.877

Table 2-29

Representative Fuel Tank Level for Emissions Modeling

A. Average July Temperatures

				Representative Tank Level % Full		
City	ASTM RVP	Low Temp.(°F)	High Temp.(°F)	3 Incomplete Surveys	GM Survey (10% Consumed Before 1st Diurnal)	GM Survey (10% Consumed After 1st Diurnal)
New York	11.5	68.0	85.2	61.12	59.12	63.35
Chicago	11.5	60.7	83.1	60.73	58.65	63.03
Phil.	11.5	66.7	86.8	61.44	59.49	63.62
Detroit	11.5	63.4	83.1	60.74	58.65	63.03
Boston	11.5	65.1	81.4	60.49	58.36	62.82
Wash. DC	11.5	69.1	88.2	61.76	59.88	63.90
Houston	10.0	72.8	93.8	61.99	60.17	64.09
Pitts.	11.5	61.3	82.5	60.64	58.53	62.95
Gr. CT	11.5	61.2	84.1	60.91	58.86	63.17
Population Weighted Avg.				61.06	59.05	63.31

Avg. = 61.18

B. Ozone Design Value Temperatures

				Representative Tank Level % Full		
City	ASTM RVP	Low Temp.(°F)	High Temp.(°F)	3 Incomplete Surveys	GM Survey (10% Consumed Before 1st Diurnal)	GM Survey (10% Consumed After 1st Diurnal)
New York	11.5	72	92	62.86	61.19	64.83
Chicago	11.5	77	95	64.05	62.59	65.83
Phil.	11.5	62	87	61.50	59.56	63.67
Detroit	11.5	66	87	61.48	59.55	63.66
Boston	11.5	73	97	65.21	63.93	66.81
Wash. DC	11.5	62	85	61.07	59.06	63.31
Houston	10.0	76	93	61.85	60.01	63.98
Pitts.	11.5	64	87	61.49	59.55	63.66
Gt. CT	11.5	72	90	62.23	60.45	64.30
Population Weighted Avg.				62.71	61.01	64.70

Avg. = 62.86

(depending on if the initial ten percent of the fuel in the tank is consumed before or after the first diurnal). Using the three incomplete surveys gave a value of 62.71 percent full. It should be stressed that these three values obtained from the different refueling surveys lie quite closely together. Since the GM survey data was most complete a final value of 62.86 percent full was determined, the average of the two extremes. Similarly, using average July temperatures, an average value of 61.18 percent full was determined. By using these fuel tank levels with city specific dispensed fuel RVP and temperatures, one can make a reasonable adjustment for the effects of weathering and in-use refueling patterns in estimations of fleet emissions, assuming that the results of the refueling surveys are representative.

Because of the scarcity of data on these subjects, and discrepancies between existing data sets, the results of this model are somewhat uncertain. For example, the different refueling surveys used in this study are in some disagreement over the fraction of vehicles completely refueled. The Exxon and GM surveys show between 60 and 70 percent complete fills, while the two surveys by Scott Environmental Technology, Inc. show 91 percent and 16 percent complete fills, respectively. Since it is difficult to say which survey best represents in-use refueling patterns, and since there is a great deal of discrepancy between the two Scott surveys, it was beneficial to evaluate the effect that each of the extremes had on the results of our model. Therefore, two additional distributions of vehicle situations were generated, one based on the survey with the lowest fraction (16 percent) of fillups, and one based on the survey with the highest fraction (91 percent) of fillups.

Calculations were performed which examined the sensitivity of the model's results to these refueling survey differences. Using Detroit temperatures and fuel RVP, the representative fuel tank level calculated ranged from 54.8 percent full for the survey with 16 percent fillups to 65.1 percent full for the survey with 91 percent fillups. Thus even these vastly different survey results affect the representative fuel tank level by only about ten percent.

Another possible source of error (in the evaluation of the three incomplete surveys only) is the assumption that the fuel tank level before partial fills only ranges between 10 percent and 40 percent full. It may be possible that a number of fuel tanks range from 50 percent full to 80 percent full before partial fills. On the other hand, it may be possible that those who don't fill their tanks completely always let their tanks run down to ten percent full before they refuel. Although neither of these scenarios is likely the actual case, the actual case should lie somewhere between them. Therefore, two more vehicle distributions were generated using the sum of all three incomplete surveys, one based on the assumption that it is equally likely for a partial fill to start at anywhere from ten percent full to 80 percent full, and one assuming that all partial fills begin with a ten percent full tank. Once again the results of the model using these two vehicle distributions for the city of Detroit showed little difference (less than seven percent) in the fuel tank level determined.

Other factors which may contribute to the uncertainty of the results of the model include the uncertainty over how much fuel, on the average, is consumed before the first diurnal is experienced. The scarcity of both on-road weathering data and of evaporative emissions data as a function of various temperatures and fill levels also adds uncertainty to the results. As more testing is performed in these areas, however, these uncertainties may disappear.

In summary, it seems reasonably accurate to state that the effect of weathering and the variability in in-use fuel tank levels can be incorporated into average fleet evaporative emissions modeling by using city specific fuel RVP and temperatures and assuming a fuel tank level of 62.86 percent full with ozone design value day temperatures and 61.18 percent full with average July temperatures. Variance of this representative tank level from city to city was negligible. Since our diurnal test procedure is intended to be 'worst-case' in nature, a fuel tank level of 40 percent full (which would give higher emissions than a 60 percent full tank) is used in certifying new vehicles. A more detailed discussion into how the effects of weathering, city-specific temperatures, and in-use fuel tank levels relate to the FTP is reserved for Appendix 6-A.

e. RVP and Temperature Variability

The evaporative emissions model used for this analysis to predict in-use emissions is partly a function of RVP and temperature. The values chosen for RVP and temperature inputs are important and need to reflect the conditions for which the model is being used. Design value day temperatures and average RVP are used for environmental analyses (i.e., inventories, future ozone-compliance), whereas average July temperatures and average July RVP are used for economic analyses (i.e., evaporative recovery credit). The basis for these assumptions are explained in greater detail in Section II of Chapter 3.

The use of average in-use RVPs and average July temperatures as inputs to the evaporative emissions model tends to underestimate average evaporative emissions due to the non-linearity of evaporative emissions with RVP and temperature. For example, the average of the evaporative emissions (sum of one hot-soak and one diurnal) from a vehicle tested over the FTP on a 9.0 psi and an 11.8 psi fuel is greater than the evaporative emissions on a 10.4 psi fuel. The following section will describe how the evaporative emissions model is adjusted through the adjustment of the fuel tank level to account for in-use RVP variability in the case of the environmental analyses, and both in-use RVP variability and daily temperature variability in the case of the economic analyses.

i. RVP Variability

The city-specific RVP used in the evaporative emissions model is 1) the average RVP of the non-alcohol containing unleaded fuels based on the Summer 1985 MVMA National Gasoline Survey for the specific city or nearest available city or 2) the ASTM limit for that city, whichever is higher. However, as the survey results show, RVP variability between service stations can be substantial. A typical range between measured low and high RVPs is 1.5 psi based on the MVMA survey.

To account for this in-use RVP variability effect on in-use evaporative emissions, the evaporative emission model was run for both the environmental and economic analyses for eight cities. Only the diurnal model was run since hot-soak emissions are more a linear function of RVP than diurnal emissions and thus are not affected to as great an extent by RVP variability.

The first run, used to account for the RVP variability effect in the environmental analyses, was based on the ozone design value day temperatures and corresponding fuel tank level of 62.86 percent as determined previously in the section on fuel weathering and fuel tank level variability. UDIs were calculated at each survey RVP, and the non-tampered emissions were projected assuming the 2010 fuel-injected/carbureted vehicle mix of 0.888/0.112. Table 2-30 presents the analysis for Dallas with ozone design value day temperatures. From the average of the non-tampered diurnal emissions, the UDI which yields this average diurnal emission value was determined. Using the average RVP and ozone design value day temperatures, and the back-calculated UDI from the average emissions, the RVP variability adjusted fuel tank level was determined as shown in Table 2-30. In other words, an adjusted in-use fuel tank level was calculated which, in combination with the ozone design value day temperatures and average RVP, yields the true emissions average for environmental analyses.

The second run, used to account for the RVP variability in the effect in the economic analyses, was based on the 30-year

Table 2-30

RVP Variability Effect on In-Use Diurnal Emissions in Dallas (Ozone Design Value Day Temperatures)

RVP (psi)	UDI**	Non-Tampered Diurnal* Emissions (g/test)
10.1	1.6116	5.073
10.2	1.6646	5.467
10.8	2.0311	8.689
10.4	1.7769	6.363
10.6	1.8987	7.426
10.1	1.6116	5.073
10.0	1.5607	4.711
9.8	1.4641	4.070
10.8	2.0311	8.689
10.0	1.5607	4.711
10.4	1.7769	6.363
10.1	1.6116	5.073

Average emissions = 5.976 g/test - UDI which yields this average emission result is 1.7296

$$\frac{\text{RVP Adjusted V}}{\text{8.4 gallon}} = \frac{1.7296}{1.7605^{***}}$$

RVP Adjusted V = 8.253 gallons

$$\text{RVP Adjusted Fuel Tank Level} = \frac{16 - 8.253 + 2}{16} \times 100 = 60.9\%$$

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* Weighted for 2010 vehicle mix, 88.8 percent FI, 11.2 percent carbureted.

** Calculated at 62.86 percent full tank, T_1 = 76°F, T_2 = 96°F.

*** UDI at average survey RVP, and ozone design value day temperatures.

average July minimum and maximum temperatures and corresponding fuel tank level of 61.18 percent also determined in the previous section on fuel weathering and fuel tank level variability. Again, UDIs were calculated at each survey RVP, and the non-tampered emissions were projected assuming the 2010 fuel-injected/carbureted vehicle mix of 0.888/0.112. From the average of the non-tampered diurnal emissions, the UDI which yields this average diurnal emission value was determined. Using the average RVP and 30-year average July temperatures, and the back-calculated UDI from the average emissions, the RVP variability adjusted fuel tank level was determined. The July average day adjusted fuel tank level still needs to be adjusted for temperature variability below.

Table 2-31 contains a summary of the RVP variability fuel tank level calculations for all eight cities for both the environmental analyses (based on ozone design value day temperatures) and the economic analyses (based on 30-year average July temperatures). The ozone design value day adjusted fuel tank level of 61 percent is used in MOBILE3 for the city-specific environmental analyses. The July average day adjusted fuel tank level of 60 percent is adjusted for temperature variability as follows.

ii. Temperature Variability

The city-specific temperatures used for the economic analyses (evaporative recovery credit runs) are 30-year average daily July minimum and maximum temperatures for the specific city or nearest available city. However, as with average RVP, using the average daily temperatures instead of actual daily temperatures tends to underestimate in-use diurnal emissions because of the non-linearity of diurnal emissions with temperature. Typical differences between the daily July temperatures and the 30-year average July daily temperatures are five-ten degrees when comparing minimum temperatures as well as maximum temperatures.

To account for the daily temperature variability effect on in-use evaporative emissions, the diurnal evaporative emissions model was run for five cities at daily July 1985 minimum and maximum temperature conditions and also at the average minimum and maximum temperatures for that month.[43] UDIs were calculated for each day, and the non-tampered emissions were projected assuming the 2010 fuel-injected/carbureted vehicle mix of 0.888/0.112. Table 2-32 presents the temperature variability analysis for Boston. From the average of the daily non-tampered emissions, the UDI which yields this average diurnal emission value was determined. Using the average of the July 1985 daily temperatures, average RVP, and the back calculated UDI from the daily average emissions, the

Table 2-31

In-Use Fuel Tank Level
After In-Use RVP Variability is Figured In

Environmental Analyses
(Design Value Day Temperatures)

City	Adjusted Fuel Tank Level (%)
Atlanta	61.3
Dallas	60.9
Denver	60.9
Detroit	61.2
Kansas City	62.2
Miami	60.9
New York	62.1
Phoenix	62.5
Average*	61.5%

Economic Analyses
(July Average Temperatures)

City	Adjusted Fuel Tank Level (%)
Atlanta	58.9
Dallas	59.1
Denver	59.2
Detroit	59.0
Kansas City	60.6
Miami	59.7
New York	60.4
Phoenix	60.9
Average	59.7%

---

* Final fuel tank level used in city specific MOBILE3 environmental analysis runs.

Table 2-32

Daily July Temperature Variability Effect on In-Use Diurnal Emissions in Boston (July Average RVP)

Date	T_1 (°F)	T_2 (°F)	UDI[1]	Non-Tampered Diurnal Emissions[2] (g/test)
1	54	69	0.5197	0.950
2	59	77	0.8499	1.391
3	62	81	1.0696	2.071
4	66	85	1.3158	3.201
5	64	84	1.2865	3.047
6	68	85	1.2289	2.758
7	69	86	1.2978	3.105
8	63	81	1.0341	1.940
9	62	80	0.9836	1.768
10	68	86	1.3444	3.358
11	69	85	1.1823	2.540
12	64	79	0.8299	1.344
13	62	82	1.1605	2.443
14	66	86	1.4313	3.865
15	71	85	1.0821	2.119
16	73	81	0.5738	0.974
17	66	76	0.5314	0.954
18	61	79	0.9363	1.621
19	64	88	1.7651	6.265
20	72	92	2.0256	8.635
21	70	83	0.9227	1.582
22	65	87	1.5950	4.953
23	63	79	0.8669	1.432
24	61	83	1.2907	3.069
25	61	86	1.6170	5.112
26	72	80	0.5444	0.959
27	69	79	0.6171	1.007
28	63	73	0.4602	0.944
29	62	84	1.3590	3.440
30	68	88	1.5989	4.981
31	62	69	0.2853	0.944
Avg.	65	82		2.670 – UDI which yields this average emission result is 1.2104

$$\frac{\text{Temperature Adjusted V}}{\text{8.445 gallon}} = \frac{1.2104}{1.0493\,[3]}$$

Temperature Adjusted V = 9.741 gallons

$$\text{Temperature Adjusted Fuel Tank Level} = \frac{16 - 9.741 + 2}{16} \times 100 = 51.6\%$$

---

[1] Calculated at 59.72 percent full tank, and RVP = 11.5 psi.

[2] Weighted for 2010 vehicle mix, 88.8 percent Fuel-Injected, 11.2 percent Carbureted.

[3] UDI at average survey RVP, and average July 1985 temperatures.

temperature variability adjusted fuel tank level was determined as shown in Table 2-32. In other words, an adjusted in-use fuel tank level was calculated which, in combination with the average July minimum and maximum temperatures and average RVP, yields the true emissions average for economic analyses.

Table 2-33 contains a summary of the temperature variability fuel tank level calculations for all five cities. The average temperature adjusted fuel tank level of 53 percent is used in MOBILE3 for the city-specific economic analyses.

f. Emission Factors Under Various Control Scenarios

The evaporative emission factors used for this analysis are city-specific. Each city included has specific RVP, temperature, and alcohol blend fraction inputs which are presented in Chapter 3. This section is intended to show the effects of volatility control on evaporative emissions in three example cities. The three cities chosen, Houston, New York, and Boston, represent urban areas whose ozone design value day temperatures and in-use or ASTM RVP conditions place them in the low, average, and high categories, respectively, for potential evaporative emissions, compared to all the areas analyzed.

Table 2-34 contains the RVP and temperature information necessary for these three cities to calculate the evaporative emissions potential. The UDI and adjusted RVP used in the diurnal and hot-soak equations of the evaporative emissions model are also listed in Table 2-34. Both current conditions, and control of in-use RVP to 9.0 psi in ASTM Class C areas (with a proportional reduction of RVP in other ASTM classes) are presented.

Based on the UDI and adjusted RVP, Table 2-35 presents the predicted in-use evaportive emissions and reductions by fuel metering type and the hot-soak and diurnal breakdown. The rates listed are for 1981+ light-duty vehicles only, with tampering included (based on an average tampering rate at 40,000 miles). The emissions are calculated from the equations listed in Appendix 2-A.

Certain trends exist for the absolute diurnal and hot-soak emissions. Diurnal emissions increase with increasing UDI, which as already explained, is a function of RVP, the diurnal temperatures and tank fill level. Hot-soak emissions, by definition of the model, are equal for any city at its ASTM limit. In other words, hot-soak emissions in Houston (ASTM Class B in July) on a 10.0 psi RVP fuel would be assumed to be equal to hot-soak emissions in Boston (ASTM Class C in July) on a 11.5 psi RVP fuel to account for temperature differences between ASTM class areas.

Table 2-33

In-Use Fuel Tank Level After RVP and Temperature Variability Are Figured In for Economic Analyses (July Average RVPs and Temperatures)

City	Adjusted Fuel Tank Level (%)
Atlanta	51.6
Boston	51.6
Detroit	51.2
Salt Lake City	52.8
San Antonio	58.1
Average*	53.1%

---

* Final fuel tank level used in city specific MOBILE3 economic analysis runs.

Table 2-34

City-Specific Evaporative Emissions Model Inputs

City	RVP(psi)	T_1(°F)	T_2(°F)	UDI	Adj. RVP
Houston	10.5	76	93	1.3818	12.1
New York	11.5	72	92	1.9766	11.5
Boston	11.5	73	97	3.0175	11.5
Houston	7.8	76	93	0.5982	9.0
New York	9.0	72	92	0.9177	9.0
Boston	9.0	73	97	1.3030	9.0

Table 2-35

City-Specific Emission Factors (g/test)

City	In-Use RVP	1981+ LDV Evaporative Emission Factor CARB DI	CARB HS	FI DI	FI HS
Houston	10.5	5.38	5.34	4.05	3.44
New York	11.5	9.86	4.57	8.77	2.87
Boston	11.5	20.24	4.57	22.66	2.87
Houston	7.8	2.70	2.64	1.94	1.09
New York	9.0	2.99	2.64	2.20	1.09
Boston	9.0	4.86	2.64	3.61	1.09

Evaporative Emission Factor Reductions* (g/test)

City	CARB DI	CARB HS	FI DI	FI HS
Houston	2.68(-50%)	2.80(-52%)	2.11(-52%)	2.35(-68%)
New York	6.87(-70%)	1.93(-42%)	6.57(-75%)	1.78(-62%)
Boston	15.38(-76%)	1.93(-42%)	19.05(-84%)	1.78(-62%)

---

* Both the absolute reductions and the percent reductions are for reducing in-use RVP from current or ASTM RVP levels to 9.0 psi in Class C Areas (proportional RVP reductions in non-class C areas.)

Patterns also exist for both the absolute evaporative emission reductions, and percent reductions. The reduction in diurnal emissions, both absolute and percent comparisons, is greater for cities with higher RVP fuels given the same proportional reduction from ASTM RVP. The reduction in hot-soak emissions is equal for all cities when RVP is proportionately reduced from ASTM levels. For these three cities, the predicted hot-soak emission reduction for Houston is higher than for New York or Boston, because the RVP in Houston was above ASTM, and therefore the reduction is also greater.

Although actual reductions will vary from city to city, the estimates shown in the bottom half of Table 2-35 offer a good range for this reduction in volatility for all of the cities in this analysis. Emission reductions from other vehicle classes and pre-1981 light-duty vehicles will be different also. Chapter 3 will present the nationwide emission inventories which are a population weighted average of the product of the separate city emission factors and the city's vehicle miles travelled.

g. Control of $\%_{160}$ of Fuels

As already stated, volatility controls of certification and in-use fuels are options for reducing HC emissions from motor vehicles. In previous sections, the effects of controlling the RVP of certification and in-use fuels on HC emission factors were discussed. Another important volatility parameter of certification and in-use fuels which could be controlled is a mid-range volatility characteristic, such as the percent evaporated at 160°F ($\%_{160}$). The $\%_{160}$ value has gathered attention because experimental work has shown the maximum temperature in the carburetor after engine shut-off to be around 160°F under standard test conditions.

The purpose of this section is to develop the emission effects of controlling the $\%_{160}$ value of in-use fuels. The following section will discuss the approach taken with respect to control of the $\%_{160}$ of certification fuel. Based on the emissions effects derived in this section and the costs associated with the control of the $\%_{160}$ point derived in Chapter 5, the cost effectiveness of controlling the $\%_{160}$ of in-use fuels will be presented later in Chapter 6.

i. Certification Fuel Control

Control of the $\%_{160}$ of certification fuel is the vehicle-related solution to the emission effect of the $\%_{160}$. The goal is to match the distillation properties of certification fuel to in-use fuel distillation properties at a given RVP level. Currently, no specifications for $\%_{160}$ of the certification fuel exist, however, target ranges for other distillation points are specified which limit the $\%_{160}$ to between 20 and 30 percent approximately.

The distillation properties of current in-use fuels and EF test fuels are similar when compared at similar RVPs. Because of this similarity in properties, the EF results already account for the effect of the $\%_{160}$ on emissions along with the effect of RVP. Also, the vehicle related costs of certification fuel $\%_{160}$ control (i.e., a larger canister) are already included in the vehicle cost estimates which will be developed in Chapter 4. Therefore, the cost effectiveness results which will be presented in Chapter 6 include the certification fuel $\%_{160}$ control effect. This means that specifying a range for the $\%_{160}$ point of the certification fuel (or a cap based on current in-use fuel properties) can be a cost effective approach to controlling evaporative emissions depending upon the certification RVP level chosen.

ii. In-Use Fuel Control

Control of the $\%_{160}$ of in-use fuels is the fuel-related solution to the emission effect of the $\%_{160}$. Hot-soak emissions of carbureted vehicles, and not the hot-soak emissions of fuel-injected vehicles are affected by control of the $\%_{160}$ point. This is due to the differences between the two fuel metering systems. In carbureted vehicles, fuel is stored in the carburetor bowl before distribution to the cylinders. After the engine is turned off, the fuel remaining in the bowl is heated due to the dissipation of engine heat, and fuel in the carburetor bowl essentially undergoes a simple distillation. These evaporated hydrocarbons are the primary source of carbureted hot-soak emissions. In fuel-injected vehicles, the fuel is injected to the engine through a pressurized and sealed system and is not susceptible to distillation.

Diurnal emissions of fuel-injected and carbureted vehicles are not affected to any extent, since diurnal vapor generation is dependent on the RVP of the fuel rather than the $\%_{160}$ point. (RVP is a measurement of the volatility at 100°F which is more representative of the typical maximum diurnal tank temperature under standard test conditions.) It should be noted that the $\%_{160}$ point can influence the load on the canister at the start of the diurnal test and thus has the potential to effect the measured emissions during the diurnal. However, this effect has been found to be weak compared to the RVP effect.[44]

For tampered vehicles (i.e., uncontrolled emissions), it was assumed only the hot-soak emissions from carbureted vehicles would be affected. It is possible that evaporative emissions from some tampered fuel-injected vehicles could be affected, for example, vehicles with broken or missing gaskets. However, the number of vehicles affected would be very small and the effect on fleet emissions likewise. Therefore, only the effect of the $\%_{160}$ point on carbureted hot-soak losses will be incorporated into the predicted emission reductions for tampered vehicles.

The experimental emissions data was obtained from a program carried out by Automotive Testing Laboratories (ATL) under contract to the EPA.[45] Vehicles were tested on four fuels, a pair of 9.2 psi fuels and a pair of 10.9 psi fuels, one fuel of each pair having a $\%_{160}$ point of approximately 25 percent and the other fuel with a $\%_{160}$ point of approximately 40 percent. Both evaporative and exhaust emissions were measured on all vehicles. Table 2-36 contains the paired t-test statistical analysis of the ATL hot-soak emissions versus fuel $\%_{160}$ at constant RVP by fuel metering system. The significance (α) verifies a relationship between $\%_{160}$ and carbureted hot-soak emissions, and lack of a relationship between $\%_{160}$ and fuel-injected hot-soak emissions (at a confidence level of 95 percent).

Hot-Soak results of twenty-two carbureted vehicles (all model year 1981) tested on the 10.9 psi fuels were used in this analysis and are listed in Table 2-37. The 10.9 psi RVP fuel emissions results were analyzed instead of the 9.2 psi RVP fuel emissions results because a greater effect of $\%_{160}$ on evaporative emissions would be expected on the higher volatility fuel. Therefore the cost effectiveness results, which will be presented in Chapter 6, are as low as could be expected. Control of RVP to the 9.0 to 10.0 psi range would increase the $/ton figures by 10 to 20 percent.

Two different approaches were taken in extrapolating the effect of the $\%_{160}$ on hot-soak emissions to in-use emissions, an additive approach and a multiplicative approach. The additive approach uses the actual increase in ATL hot-soak emissions and assumes the increase would be the same for EF hot-soak emissions. The multiplicative approach applies the percentage change in ATL hot-soak emissions from a base test fuel with $\%_{160}$ equal to 35 percent, to non-tampered EF hot-soak emissions at 11.7 psi to estimate the increase in EF hot-soak emissions. The multiplicative approach is one possible way to address the discrepancy between hot-soak emissions measured at ATL and hot-soak emissions measured under the same test procedure at the EPA laboratory in Ann Arbor.[44]

Table 2-36

Paired T-Test Analysis of ATL $\%_{160}$ Hot-Soak Emissions

Fuel Metering System	N	RVP (psi)	Nominal $\%_{160}$	Mean (g/test)	Mean Difference	Standard Deviation	T-stat	Significance (α)
CARB	22	9.2	25.0	0.98	-0.30455	0.76553	-1.8660	0.038
			40.0	1.29				
		10.9	25.0	1.25	-0.33818	0.88190	-1.7986	0.043
			40.0	1.59				
FI	7	9.2	25.0	0.37	-0.01429	0.11717	-0.3226	0.379
			40.0	0.39				
		10.9	25.0	0.45	-0.03571	0.18519	-0.5102	0.314
			40.0	0.48				

Table 2-37

ATL Carbureted Hot-Soak Emissions on 10.9 psi RVP Fuel
(g/test)

ATL Vehicle #	$\%_{160} = 22.6$	$\%_{160} = 39.0$
201	0.50	1.31
202	0.90	1.93
203	0.53	0.59
204	0.83	1.67
205	1.17	1.08
206	0.82	0.90
207	1.07	1.23
208	0.95	1.35
209	0.96	1.02
210	1.51	2.62
211	1.18	0.85
212	1.14	1.02
213	0.72	0.86
214	3.84	7.51
215	1.22	1.46
216	1.00	1.20
217	0.61	0.80
218	3.79	2.95
219	1.25	1.02
230	1.74	1.36
239	0.78	1.33
240	1.01	0.89
Average	1.25 g/test	1.59 g/test

For both the additive and multiplicative approaches, two estimates of hot-soak emissions versus fuel $\%_{160}$ values were derived. For the first additive estimate, a straight line was drawn through the two average ATL data points. However, based on the general design properties of evaporative control systems, this approximation would likely underestimate the actual emission reductions. Therefore for the second estimate, a curve was drawn through the two average ATL data points which would better approximate the emission reductions, though possibly on the high side. The two curves result in a range for the predicted emissions reduction in the additive approach.

The straight line would be the result if the measured hot-soak losses (i.e., controlled emissions) were a linear function of uncontrolled emissions, which in turn should be proportional to the $\%_{160}$ point. However, since the incremental effectiveness of the charcoal canister decreases as uncontrolled emissions increase, hot-soak emissions would most likely be an upward sloping non-linear function of the $\%_{160}$ point. In other words, for fuels with relatively low $\%_{160}$ points, the charcoal would be able to handle the additional HC vapor loading and the hot-soak emissions would be lower than predicted by the straight-line method. For fuels with relatively high $\%_{160}$ points, the charcoal would become saturated with HC vapors and the hot-soak emissions would be greater than predicted by the straight-line method. As this function is unknown, a curve was drawn to represent a reasonable upper limit of the degree of curvature.

To draw a worst-case curve, a similar relationship was assumed to hold between diurnal emissions and fuel RVP as holds between hot-soak emissions and the $\%_{160}$ point. This should be a reasonable upper limit for two reasons. One, RVP is the most appropriate fuel parameter for diurnal emissions as $\%_{160}$ is for hot-soak emissions. Two, in-use diurnal emissions increase more between 9 and 11.5 psi than hot-soak emissions increase between $\%_{160}$ values of 25 and 40 percent, indicating a stronger movement from an unsaturated to a saturated condition. Thus, the diurnal emissions of carbureted vehicles versus fuel RVP from the EF data base were used to determine a third intermediate point for the hot-soak emissions versus $\%_{160}$ curve.

Table 2-38 presents the numbers used to determine the intermediate point of the hot-soak curve. The fraction of the increase in diurnal emissions in going from 9.0 psi to 10.4 psi as compared to going from 9.0 psi to 11.7 psi (35 percent of the total diurnal increase) was applied to the increase in average hot-soak emissions measured on the two different ATL fuels. The intermediate hot-soak result was graphed at the $\%_{160}$ point of 31.1 percent, which is equidistant between 22.6

Table 2-38

Values Used to Curve Fit Average ATL Hot-Soak Emissions as a Function of $\%_{160}$

	RVP (psi)	Non-Tampered EF Carbureted Diurnal Emissions[1] (g/test)	
	9.0	2.60	
52% <			> 35%
	10.4	5.29	
48% <			> 65%
	11.7	10.33	

	$\%_{160}$	ATL Carbureted Hot-Soak Emissions (g/test)	
	22.6	1.25[2]	
52% <			> 35%
	31.1[3]	1.37[3]	
48% <			> 65%
	39.0	1.59[2]	

---

[1] Actual EF data averages as listed in Table 2-12.

[2] Average ATL emissions.

[3] Predicted ATL emissions based on the increase in carbureted EF diurnal emissions as a function of RVP for the intermediate RVP level.

percent and 39 percent as 10.4 psi is between 9.0 psi and 11.7 psi. Figure 2-15 presents the resulting additive functions of ATL hot-soak emissions versus the $\%_{160}$ point and can be used to predict the decrease in hot-soak emissions of non-tampered carbureted EF vehicles from reducing the $\%_{160}$ point of any in-use gasoline or alcohol blend.

For the multiplicative approach, the percent change in hot-soak emissions was determined from the two estimates of Figure 2-15 from a base fuel with a $\%_{160}$ value of 35 percent. The base fuel in this analysis is the high volatility EF test fuel which had a $\%_{160}$ value of around 35 percent. Table 2-39 presents the ATL emissions predicted under both the straight line and curve methods at various $\%_{160}$ values from Figure 2-15 and the percentage change from the base fuel. These percentage changes were applied to the EF non-tampered data (4.26 g/test on 11.7 psi fuel) and are also listed in Table 2-39. Figure 2-16 presents the resulting multiplicative functions of hot-soak emissions versus the $\%_{160}$ point, and can be used to predict the decrease in hot-soak emissions of non-tampered carbureted EF vehicles from reducing the $\%_{160}$ point of any in-use gasoline or alcohol blend. A different analysis of the effect of $\%_{160}$ on in-use emissions also resulted in a similar curve lying between the straight-line and worst-case estimates as derived above.[44]

As previously mentioned, control of the $\%_{160}$ point of in-use fuels would also cause emission reductions from tampered carbureted vehicles. Since emissions from tampered vehicles are uncontrolled emissions, the reduction in hot-soak emissions should be proportional to the reduction in the $\%_{160}$ point of the test fuel upon which the emission estimates were based. For example, reducing the $\%_{160}$ point of gasohol from 35 percent to 25 percent should result in approximately a 29 percent decrease (10/35 = 0.29) in tampered carbureted vehicle hot-soak emissions. Based on the uncontrolled hot-soak emission rates listed in Table 2-A-6 of Appendix 2-A, the hot-soak emission reduction in lowering the $\%_{160}$ value by ten percent (i.e. 45 to 35 or 35 to 25) from a tampered carbureted vehicle tested on a high volatility (11.5 psi) EF test fuel would be 4.99 g/test.

The effects of the $\%_{160}$ on fleeetwide emissions will be examined in Chapter 6 along with the determination of the cost-effectiveness of controlling the $\%_{160}$ of in-use fuels.

2. Exhaust Emissions

The following sections investigate the relation between fuel volatility and exhaust emissions. The first section establishes the relation, the second section discusses the

Figure 2-15

HOT-SOAK EMISSIONS versus %160

(Additive Method)

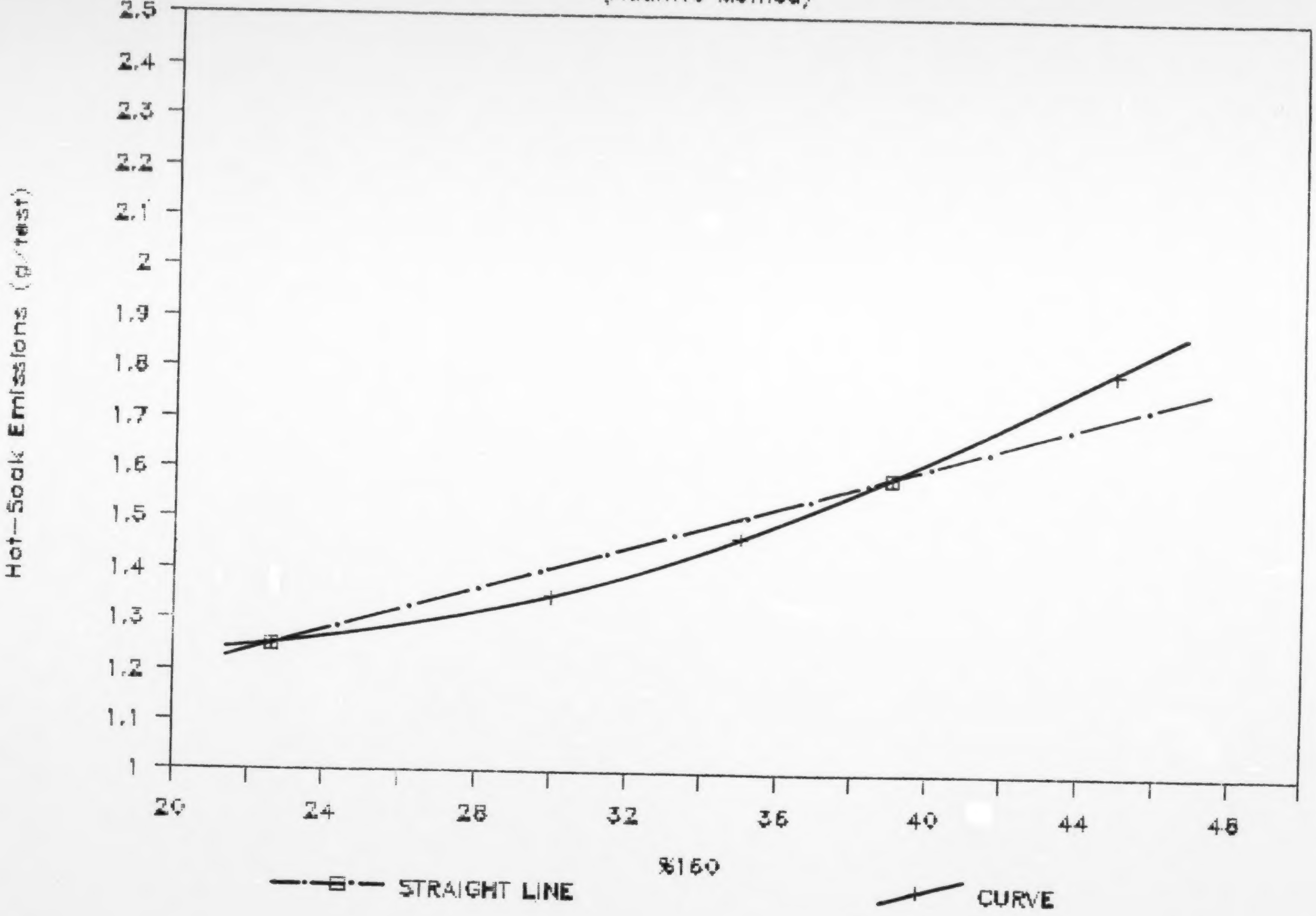


Table 2-39

Application of Percentage Change in ATL Hot-Soak Emissions to Predict EF Hot-Soak Emissions (Multiplicative Method)

Straight Line:

$\%_{160}$	Average ATL Hot-Soak Emissions[1]	Change in ATL Hot-Soak Emissions from Base	Predicted EF Hot-Soak Emissions
22.6	1.25 g/test	-16.7%	3.55 g/test
35.0	1.50	Base[2]	4.26[3]
39.0	1.59	+6.0%	4.52

Curve:

$\%_{160}$	Average ATL Hot-Soak Emissions[1]	Change in ATL Hot-Soak Emissions from Base	Predicted EF Hot-Soak Emissions
22.6	1.25 g/test	-15.0%	3.62 g/test
30.0	1.35	-8.2%	3.91
35.0	1.47	Base[2]	4.26[3]
39.0	1.59	+8.2%	4.61
45.0	1.80	+22.4%	5.21

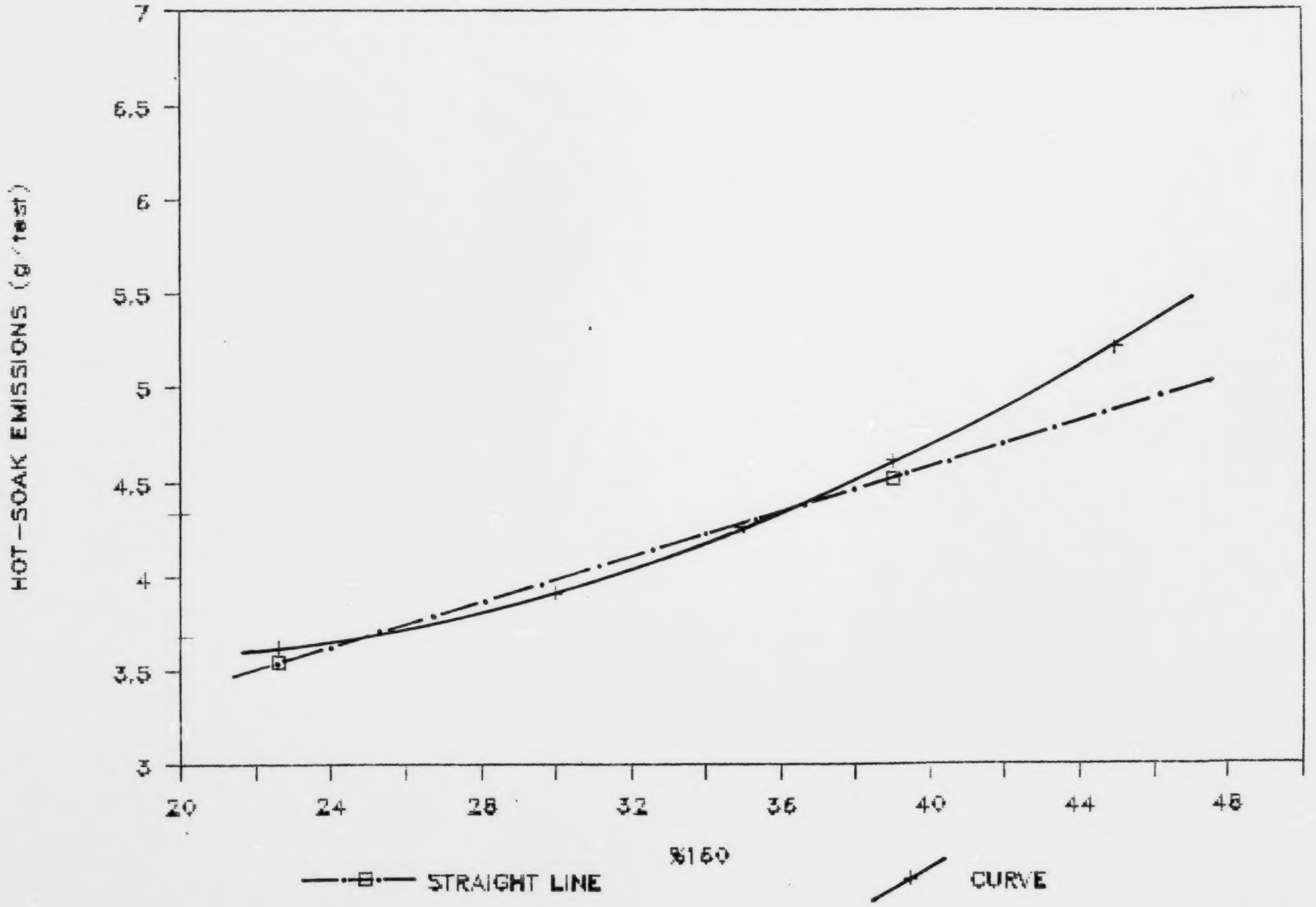
---

[1] From Figure 2-15.

[2] The 11.7 psi EF test fuel had $\%_{160}$ around 35 percent.

[3] Average EF Carbureted hot-soak emissions on 11.7 psi fuel.

Figure 2-16



HOT-SOAK EMISSIONS versus %160

(Multiplicative Method)

effect of volatility controls on vehicle emissions, and the third section investigates the possible reasons for the fuel volatility/HC exhaust emission correlation.

a. Correlation Between RVP and Exhaust Emissions

EPA's Emission Factor (EF) program includes tests for exhaust emissions as well as evaporative emissions. Prior to November of 1983, when testing was only performed using Indolene, the effect of RVP on in-use emissions was not known. Between October 1983 and July 1984, RVP appeared to have little effect on exhaust emissions.[46] However, since July 1984 (when the test sequence was improved), a significant effect has been seen, particularly that high RVP fuel increases exhaust emissions of HC and CO. No significant increase in NOx emissions with higher volatility fuels has been noted. The lack of an effect prior to July 1984 is presumed to be due to the extra purging of the in-use canister during the evaluation on Indolene, in which the HFET and various short tests were conducted prior to testing on high RVP, commercial fuel.

Insofar as metropolitan areas are in non-compliance with the NAAQS for CO, the CO emission reductions occuring with a reduction of RVP would produce a public health benefit. However, violation of the NAAQS for CO is not nearly as widespread as that for ozone. Also, the primary focus of this rulemaking is the effect of RVP on nationwide ozone NAAQS compliance. Thus, only the effect of RVP on HC exhaust emissions will be further discussed in this section. It should be remembered that some CO benefit exists with respect to RVP control.

An analysis was made of exhaust emissions versus RVP, based on a group of 322 EF cars, tested on three fuels between August 1984 and February 1986. The three fuels were tested in the following sequence: commercial fuel (11.7 psi RVP), a blend of commercial fuel and Indolene (10.5 psi), and Indolene (9.0 psi). The prep cycle prior to the diurnal test was a full LA-4 in all cases.

Cars with "large" HC exhaust emissions were found to be insensitive to fuel volatility. Apparently the problems causing these large emissions were masking the volatility effect. Therefore, the ten cars with HC emissions exceeding 4.0 g/mi (on Indolene) were excluded from the analysis. In addition, the three tampered vehicles excluded in the evaporative emission analysis were also excluded, along with one vehicle that had questionable test results (an increase in HC exhaust emissions from 0.42 to 6.48 grams/mile for Indolene and commercial fuel, respectively). This left 308 cars in the data base for the analysis. The model years for these cars were 1981 through 1984.

Table 2-40 shows the average HC exhaust emission as found in this analysis. The groups shown include carbureted (closed loop, open-loop, all carbureted), fuel-injected, and all 308 vehicles. In every case, the average HC exhaust emission increases with fuel volatility. However, since average values do not show how individual vehicles react to fuel volatility, the number of vehicles with larger HC exhaust emissions using commercial fuel than from Indolene are shown in Table 2-41. In general, 80 percent of the vehicles show larger exhaust emissions with commercial fuel than with Indolene. A Wilcoxen test showed a 0.00 percent probability that this difference was due to random error.

To quantify how the HC exhaust emissions from individual vehicles react to volatility, a Paired t statistic was calculated to find the probability, α. Vehicles are considered to show a significant exhaust difference with respect to fuel volatility when α is less than 0.05 (95 percent confidence that the exhaust differences are not due to random error). As shown by Table 2-42, all of the technology classes (fuel metering systems) have an α of 0.000. Therefore, the Paired t-Test indicates an extremely significant relation between fuel volatility and HC exhaust emissions.

As a further check on the exhaust emission/volatility correlation, the data base was further broken down into smaller groups: method of aspiration; type of fuel injection - TBI/PFI; season - summer/winter; and manufacturer - GM/Ford/Chrysler. Vehicles from other manufacturers were included in the overall database, but were too few in number for a Paired t-Test. An examination of the GM, Ford, and Chrysler subcategories show that for each group, fuel volatility causes a significant difference in HC exhaust emissions. Within these groups, only the Ford and Chrysler TBI systems indicate that RVP is not significant. Since the Chrysler TBI subgroup has only 10 vehicles, this insignificance may be caused by random test error. However, the Ford TBI subgroup was sufficiently large enough (23 vehicles) to provide confidence in the Paired t-statistic. No conclusive explanation has been found for their insignificance to fuel volatility. Insufficient canister capacity at high RVP fuels would result in the evaporated HC's breaking through the canister rather than being captured and later purged, however no relation was found between exhaust emissions and evaporative emissions.

Fuel volatility is increased during the colder temperatures of the winter season to overcome vehicle starting problems. As a result, vehicles received during the winter for testing may have a different initial canister loading than cars received during the summer. Potentially, this seasonal difference could confound the HC exhaust emission analysis, if

Table 2-40

Average HC Exhaust Emissions (g/mi)*

RVP (psi)	Carbureted			Fuel-Injected	All Vehicles
	All	Closed-Loop	Open-Loop		
9.0	0.76	0.82	0.68	0.43	0.59
10.5	0.80	0.84	0.74	0.46	0.62
11.7	0.89	0.95	0.82	0.51	0.69

---

* Data from 308 LDVs tested between August 1984 and February 1986 as part of EPA's Emission Factor program.

Table 2-41

Number of Vehicles*

RVP (psi)	Carbureted			Fuel-Injected	All Vehicles
	All	Closed-Loop	Open-Loop		
11.7>9.0**	120	69	51	119	239
Total	147	85	62	161	308
Percent**	82%	81%	82%	74%	78%

---

* Data from 308 LDVs tested between August 1984 and February 1986 as part of EPA's Emission Factor program.

** 11.7>9.0 = Number (percent) of vehicles where the HC exhaust emissions are larger for commercial fuel (11.7 psi RVP) than for Indolene (9.0 psi RVP).

Table 2-42

Paired t-Test Results*

Category	# of cars	α** for HC
All vehicles	308	0.000
FI	161	0.000
TBI	92	0.000
PFI	69	0.000
Carbureted	147	0.000
Open-loop	62	0.000
Closed-loop	87	0.000
Winter	187	0.000
Summer	121	0.000
Turbo	22	0.001
Nat'l Asp	289	0.000
Ford	75	0.000
PFI	15	0.000
TBI	23	0.306
Carb.	37	0.002
GM	116	0.000
PFI	26	0.001
TBI	49	0.004
Carb.	41	0.014
Chrysler	37	0.012
TBI	10	0.159
Carb.	27	0.020

---

* Data from 308 LDVs tested between August 1984 and February 1986 as part of EPAs Emissions Factor program.

** α =The probability that the differences seen are due to random error and not due to differences between the test conditions (i.e., commercial fuel versus Indolene). Values below 0.05 indicate significant differences.

the canisters were not adequately purged before the FTP tests. Therefore, to check the possibility of seasonal effects, separate Paired t-Tests were made for cars tested during the summer versus the winter. As shown in Table 2-42, no evidence of seasonal variation was found.

The analysis of the 308 cars in the Emission Factor data base indicate that for a majority of 1981-1984 vehicles, exhaust emissions increase with increased fuel volatility. An analysis of the exhaust emission benefits possible by in-use RVP reduction will now be made.

b. Effect of RVP Control

Exhaust hydrocarbon emissions usually increase with an increase in fuel RVP. At present, there is no limit on how high in-use RVP can go. By setting an in-use RVP limit, a reduction in HC exhaust emissions can be obtained. This "cap" could provide a temporary reduction in HC emissions until vehicles capable of handling higher RVP fuels become common throughout the fleet, or the cap could be used to permanently limit RVP and therefore reduce exhaust HC emissions without vehicle modifications.

To calculate the exhaust benefit, a linear regression of HC exhaust emissions versus actual RVPs was performed for 1981 and later model year cars. Vehicles in this age group accumulate roughly 60 percent of the total vehicle miles traveled (VMT) by LDVs, per year. The regression utilized the 322* cars from the EF data base, all of which were tested on three different RVP fuels. Due to the similarity in regression terms between the various technologies (carbureted vs. fuel-injected), all classes were grouped together. Therefore, using this 322 car data set, the slope was found to be 0.0387 g/mi/RVP with a constant of 0.593 g/mi. Using the 292 cars with HC emissions less than 1.50 g/mi (on Indolene), the slope was found to be 0.0478 g/mi/RVP with a constant of 0.0216.

To calculate the average change in HC exhaust emission with RVP, an exhaust emission correction factor (CF) was developed which normalized the data to 11.5 RVP. Therefore, at 11.5 RVP the CF is 1.0, and below 11.5 RVP the CF is less than 1.0. No upper RVP limit was imposed on the correction factor, therefore CF values greater than 1.0 are possible. However, since engines are already designed to handle 9.0 RVP fuel, the CF is reset to the 9.0 level for RVPs less than 9.0 psi.

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* To obtain the average fleet response to RVP, the regression incorporated the "high emitters" and tampered vehicles previously excluded.

Table 2-43 shows the HC exhaust emission benefits for RVPs between 8.0 and 11.5, for both data sets. Lowering in-use RVP from 11.5 to 9.0 psi results in a nine percent reduction in exhaust hydrocarbons when all the vehicles are analyzed. Considering only those vehicles with HC exhaust emissions less than 1.50 g/mi (on Indolene), the HC exhaust reduction is 21 percent. For this analysis, the effect of volatility control on exhaust emissions is based on the data set including all 322 vehicles.

Modifying the engine/evaporative system is another potential method for reducing HC exhaust emissions on future vehicles. An analysis of why the exhaust emissions are sensitive to fuel volatility is made below in order to evaluate potential modifications.

c. Potential Causes for Increased Exhaust Emissions

For a majority of existing vehicles, the change in HC exhaust emissions can be directly correlated to fuel RVP. These changes in HC exhaust emissions can be attributed to changes in HC combustion dynamics and/or to changes in catalyst efficiency - i.e. oxygen shifts causing shifts in the exhaust air/fuel ratio. While in-cylinder combustion differences between various RVP fuels may cause this exhaust difference, most manufacturers claim that the quantity of unmetered fuel* is the predominant factor.

Fuel volatility will alter the amount of unmetered fuel introduced to the engine. An increase in unmetered fuel may increase the charge density, which may then increase HC emissions by hindering combustion. In this scenario, the amount and timing of unmetered fuel becomes critical. In an alternate theory, unmetered fuel affects HC emissions by consuming excess oxygen and thereby decreasing the HC conversion efficiency in the catalytic converter. With time, the oxygen sensor should reduce the amount of metered fuel, allowing the exhaust air/fuel ratio to return to stoichiometry. However, this correction may be too slow or inadequate, allowing a net increase in HC emissions.

No conclusive and confirmed tests have been performed to show which reason(s) is/are responsible for the exhaust effect. However, various studies performed by automotive manufacturers and API, and EPA vehicle test programs can be

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* Metered fuel is the fuel introduced into the engine in specified quantities. Unmetered fuel is the unmeasured and loosely controlled fuel introduced through the canister purge and fuel tank vent lines.

Table 2-43

Exhaust Emissions versus RVP*

Entire Data Set (322 cars):

RVP	8.0	8.5	9.0	9.5	10.0	10.5	11.0	11.5
HC (g/mi)	.903	.922	.941	.961	.980	.999	1.02	1.04
CF	.907	.907	.907	.925	.944	.963	.981	1.00
% Red.	9.3	9.3	9.3	7.5	5.6	3.7	1.9	0.0

Normal Emitters** (292 cars):

RVP	8.0	8.5	9.0	9.5	10.0	10.5	11.0	11.5
HC (g/mi)	.404	.428	.452	.476	.500	.524	.547	.571
CF	.791	.791	.791	.833	.874	.916	.958	1.00
% Red.	20.9	20.9	20.9	16.7	12.6	8.4	4.2	0.0

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* Values were obtained from a linear regression of the Emission Factor data base for 1981 and later LDVs, tested between August 1984 and February 1986.

** Normal emitters are those vehicles with HC and CO exhaust emissions below 1.5 g/mi and 2.0 g/mi, respectively (Indolene fuel).

used directly or indirectly to better understand the cause. A majority of these studies indicate the exhaust effect is related to unmetered fuel. The following is a summary of two EPA programs.

The first program investigated the effects of fuel tank temperature on emissions. Automobiles are presently being designed with fuel circulation pumps that return unused fuel back to the fuel tank. Due to engine heat, the returned fuel is hot and may eventually raise the fuel tank temperature, which increases the amount of evaporated fuel which must be purged. In this study, a series of replicated FTPs, using two cars (a 1986 Buick and a 1984 Plymouth), two fuels (9.0 and 11.7 RVP), and two dynamometer cooling arrangements (EPA standard and "high" cooling) were used.[47] The "high" cooling arrangement resulted in lower tank temperature rises than shown by track tests performed by Exxon and EPA.[48,49]

With the Buick, the fuel tank temperatures and exhaust emissions were fairly constant for all conditions. Therefore this vehicle does not help to explain why exhaust emissions may change with fuel volatility.

The Plymouth however, was found to be sensitive to fuel volatility and fan arrangement. On 11.7 RVP fuel, a 55 percent reduction (1.10 to 0.50 g/mi) in HC exhaust emissions was obtained with a corresponding 19°F drop in the tank temperature rise. In another case, a similar reduction in HC exhaust emissions was obtained by plugging the purge line. Examining the exhaust CO levels can also be helpful in verifying the effect of unmetered fuel, since CO is very sensitive to the air/fuel ratio. For both fuels, the CO emissions were increased by a factor of four with the warmer fuel tank temperature.

The Plymouth test results indicate that tank heating of high RVP fuel will increase the amount of unmetered fuel, causing an increase in HC exhaust emissions. The Buick test results support the possibility of designing vehicles that can adequately manage high RVP fuel, without increased HC exhaust emissions.

In another program, the EPA tested nine cars on both 9.0 and 11.7 psi RVP fuel, with and without connections to the charcoal canister (purge lines were left unplugged).[50] The average HC and CO results, along with the number of vehicles with increased emissions are shown in Table 2-44.

With Indolene, there is basically no difference in HC exhaust emissions for the vehicles tested with and without

Table 2-44

Summary from Tampered Vehicle Study*

Test Category	Ave. HC Exhaust Emissions (g/mile)	# of Cars w/Increased HC Exhaust Emissions**	Ave. CO Exhaust Emissions (g/mile)	# of Cars w/Increased CO Exhaust Emissions**
9.0 RVP w/***	0.36	5	4.59	6
9.0 RVP w/out****	0.33	–	4.22	–
11.7 RVP w/***	0.42	8	6.93	8
11.7 RVP w/out****	0.37	7	4.53	4

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* An EPA study of nine vehicles tested on 9.0 and 11.7 RVP fuel, with and without proper connections to the charcoal canister. All disconnected vapor lines to the canister were left unplugged, as would be found in a tampered situation.

** Exhaust emissions compared to exhaust emissions with 9.0 RVP fuel and no connections to the charcoal canister.

*** w/ = with proper connections to the charcoal canister.

**** w/out = without proper connections (no connections) to the charcoal canister.

functional evaporative systems. Since the vehicles were designed to adequately purge Indolene vapors with a minimal effect on exhaust emissions, the lack of change in exhaust emissions is expected if the exhaust emission phenomena is purge related. However, with 11.7 RVP fuel, the average difference in HC exhaust emissions almost doubled. Since "high" RVP fuel causes a correspondingly larger uncontrolled evaporative emission than "low" RVP fuel, these tests may indicate that the increased hydrocarbon purge concentration (from the uncontrolled evaporative emissions) exceeded the design values, causing the larger exhaust emissions. The CO levels also support the rich combustion theory of increased exhaust emissions with increased consumption of unmetered fuel.

In both of these EPA studies, the increased HC exhaust emissions appear to be related to increases in unmetered fuel. This exhaust effect can be remedied by lowering in-use RVP to certification levels (as discussed in Chapter 3), or by redesigning vehicles to adequately manage the increase in unmetered fuel. Suggested modifications in purge control will be discussed in Chapter 4. It should be noted that some vehicles are presently insensitive to fuel volatility while other vehicles may be sensitive but still within the 0.41 g/mi standard. Therefore, these suggested modifications are not expected to be required for all new vehicles.

In addition, some vehicles may be able to reduce their fuel tank heating and subsequent canister loading by altering the placement of their fuel tank and lines relative to the exhaust pipe. The relocation will reduce fuel heating, which in turn will reduce fuel vaporization. However, due to the variability in vehicle design, along with the individual design considerations required for each model, this topic will not be developed further.

3. Refueling Emissions

Refueling emissions are the third category of vehicle HC emissions along with evaporative and exhaust emissions that are affected by fuel RVP. Refueling emissions are the emissions generated when someone purchases gasoline at the gas station and fills their gas tank.

About 90 percent of all refueling emissions consist of vapors displaced from the vehicle fuel tank by the incoming gasoline. The total mass of these emissions depends on the volume of vapor displaced and its density, which in turn are determined by the temperature of the fuel being dispensed and of the fuel already in the tank, the tank size and geometry of the tank, the volatility of the fuel, and a number of other minor factors. (The determinants of refueling emissions are discussed in greater detail in "Refueling Emissions from Uncontrolled Vehicles," an EPA technical report.[1])

Less significant sources of refueling emissions are spillage and underground tank emptying losses. Spillage occurs as a result of "splash back" from the fill pipe or the escape of gasoline from the dispensing nozzle. Underground tank emptying losses represent the escape of vapor from the vent of the service station underground storage tank. This emptying loss occurs because as fuel is pumped into the vehicle fuel tank, ambient air is ingested into the service station tank through its tank vent. This "fresh" air causes liquid fuel to evaporate in the tank until an equilibrium concentration between the vapor and liquid phases is reestablished. As this occurs, the pressure within the tank becomes greater than the atmospheric pressure. This increases the total volume of vapor in the underground tank, with the excess volume being emitted from the vent in the form of gasoline vapor emissions. The spillage and emptying loss sources each account for about five percent of the total emissions associated with the refueling process.[51] In this analysis, underground tank emptying losses are included in Stage I emissions, and only displacement and spillage losses are included in refueling emissions. This is consistent with the gasoline marketing study.[2]

The composition and amount of refueling vapors depends on their source (e.g., fuel tank displacement or spillage), and the volatility of the fuel. For example, the largest source of refueling emissions, that portion resulting from vapor displacement in the vehicle fuel tank, does not consist of fully volatilized gasoline. All available information shows that the "light-end" hydrocarbons generally evaporate more readily than the higher molecular weight hydrocarbons, and so refueling emissions are primarily light-end hydrocarbons.

The portion of refueling emissions that results from spilling gasoline, on the other hand, reflects the composition of the liquid fuel. This is due to the total evaporation of liquid fuel that is spilled. However, as noted above, it is estimated that no more than five percent of total refueling emissions currently result from fuel spillage and evaporation. Thus, the statements made with respect to the composition of refueling emissions due to vapor displacement are essentially valid for total refueling emissions as well.

The estimates for uncontrolled refueling emission factors used in this analysis are based on the information derived in the previously mentioned technical report, "Refueling Emissions from Uncontrolled Vehicles."[1] The equation is as follows.

$$\text{Refueling} = \text{Displacement} + \text{Spillage}$$

$$\text{Spillage} = 0.32 \text{ g/gallon}$$

$$\text{Displacement} = -5.909 - 0.0949\ (\Delta T) + 0.0884\ (T_D) + 0.485\ (\text{RVP}) \quad \text{(in g/gallon)}$$

where

T_D = dispensed fuel temperature

ΔT = difference between tank temperature and dispensed fuel temperature

RVP = Reid Vapor Pressure of dispensed fuel

Insufficient data were available to derive dispensed fuel temperatures on a local basis for all 61 ozone non-attainment areas, so city-specific refueling emission factors could not be generated. A nationwide-average refueling emission factor was used instead and was assumed to apply in all cities.

The refueling report identified inputs for this equation based on a summertime (five-month) analysis of available ambient and dispensed fuel temperatures and ASTM-limit RVPs weighted by state and/or regional fuel consumption. The results were a dispensed fuel temperature of 78.8°F, a difference between tank and dispensed temperature of 9.4°F and a summertime nationwide ASTM average RVP of 11.3 psi.

The 11.3 psi RVP level derived from the ASTM limits is equivalent to the 11.5 Class C RVP control case, which also represents control to the ASTM limits. The refueling RVPs for all other scenarios depicted in Table 2-45 were simply derived by multiplying the Class C RVP by the ratio of the base nationwide refueling RVP (11.3 psi) over 11.5 psi. This results in the same percentage reduction in RVP for both the refueling and evaporative emissions portions of the analysis, which reflects what is happening in-use. Table 2-45 shows the nationwide fuel RVP used in the refueling emission factor equation associated with each control scenario of interest and the resulting refueling emission factor.

The g/gallon estimates of refueling are divided by the vehicle fuel economy to determine the refueling rates on a g/mi basis, as used in MOBILE3. The top half of Table 2-46 presents the uncontrolled refueling emission factors for all vehicles by model year on an 11.5 psi fuel.

Table 2-45

Refueling Emission Rates at Various RVP Levels

(g/gallon)

Uncontrolled Class C RVP	Nationwide Average Refueling RVP	Refueling Rate
11.0 (1983)	10.8	5.7
11.7 (1988 and beyond)	11.5	6.1
Controlled Class C RVP		
11.5	11.3	6.0
11.0	10.8	5.7
10.5	10.3	5.5
10.0	9.8	5.2
9.5	9.3	5.0
9.0	8.8	4.8
8.5	8.4	4.6
8.0	7.9	4.3

Table 2-46

Nationwide LDV Uncontrolled Refueling Emission Factors on 11.5 psi RVP Gasoline (g/mi)

Model Year	Emission Factor	Model Year	Emission Factor
pre 1969	0.4803	1985	0.2629
1970	0.4803	1986	0.2574
1971	0.4959	1987	0.2542
1972	0.4919	1988	0.2510
1973	0.5000	1989	0.2480
1974	0.5000	1990	0.2440
1975	0.4518	1991	0.2402
1976	0.4094	1992	0.2355
1977	0.3910	1993	0.2319
1978	0.3588	1994	0.2293
1979	0.3546	1995	0.2251
1980	0.3065	1996	0.2210
1981	0.2864	1997	0.2179
1982	0.2760	1998	0.2148
1983	0.2760	1999	0.2118
1984	0.2669	2000+	0.2096

Nationwide LDV Controlled Refueling Emissions Factors on 11.5 psi RVP Gasoline (g/mi)

Model Year	Emission Factor	Model Year	Emission Factor
1990	0.0192	1996	0.0174
1991	0.0189	1997	0.0171
1992	0.0185	1998	0.0169
1993	0.0182	1999	0.0167
1994	0.0180	2000+	0.0165
1995	0.0177		

Table 2-46 (continued)

Nationwide LDT1 & LDT2 Uncontrolled Refueling Emission Factors on 11.5 psi RVP Gasoline (g/mi)

Model Year	Emission Factor	Model Year	Emission Factor
pre 1969	0.5496	1985	0.3446
1970	0.5496	1986	0.3408
1971	0.5701	1987	0.3370
1972	0.5648	1988	0.3333
1973	0.5755	1989	0.3315
1974	0.5755	1990	0.3280
1975	0.5126	1991	0.3245
1976	0.4959	1992	0.3228
1977	0.4586	1993	0.3210
1978	0.4692	1994	0.3210
1979	0.4841	1995	0.3177
1980	0.3861	1996	0.3128
1981	0.3610	1997	0.3096
1982	0.3547	1998	0.3035
1983	0.3486	1999	0.3005
1984	0.3486	2000+	0.2961

Nationwide LDT1 & LDT2 Controlled Refueling Emission Factors on 11.5 psi RVP Gasoline (g/mi)

Model Year	Emission Factor	Model Year	Emission Factor
1990	0.0260	1996	0.0248
1991	0.0257	1997	0.0246
1992	0.0256	1998	0.0241
1993	0.0254	1999	0.0238
1994	0.0254	2000+	0.0235
1995	0.0252		

Table 2-46 (continued)

Nationwide HDV Uncontrolled Refueling Emission Factors on 11.5 psi RVP Gasoline (g/mi)

Model Year	Emission Factor	Model Year	Emission Factor
pre 1969	0.9457	1985	0.6094
1970	0.9457	1986	0.6082
1971	1.0033	1987	0.6070
1972	1.0702	1988	0.6022
1973	1.0000	1989	0.5986
1974	0.9385	1990	0.5945
1975	0.8815	1991	0.5905
1976	0.8957	1992	0.5854
1977	0.8520	1993	0.5749
1978	0.7881	1994	0.5690
1979	0.7559	1995	0.5653
1980	0.6971	1996	0.5607
1981	0.6711	1997	0.5612
1982	0.6455	1998	0.5576
1983	0.6131	1999	0.5546
1984	0.6094	2000+	0.5505

Nationwide HDV Controlled Refueling Emissions Factors on 11.5 psi RVP Gasoline (g/mi)

Model Year	Emission Factor	Model Year	Emission Factor
1990	0.0467	1996	0.0441
1991	0.0464	1997	0.0441
1992	0.0460	1998	0.0438
1993	0.0452	1999	0.0436
1994	0.0447	2000+	0.0433
1995	0.0444		

As is discussed later in Chapter 3, the MOBILE3 emission model is run under two different refueling scenarios. The first scenario assumes no control of refueling emissions on any vehicles. The second scenario assumes that on-board technology is required by regulation on all 1990 and later model years gasoline vehicles.

A typical on-board system would be expected to consist, at least in part, of a charcoal canister and a fill-neck seal. The fill-neck seal prevents refueling emissions from entering the atmosphere, and the charcoal canister traps the refueling emissions to be burned in the engine later. The on-board system eliminates the great majority of both displacement and spillage losses. The control efficiency of a properly operating on-board system is assumed to be 97 percent. Tampering, malmaintenance and defects, and system deterioration lower the in-use fleetwide efficiency which MOBILE3 calculates. The controlled refueling emission factors are presented in the bottom half of Table 2-46 for all 1990 and later vehicles by model year.

B. Alcohol Blend-Fueled Vehicles

The addition of ethanol and/or methanol to gasoline affects both evaporative and exhaust emissions. When dealing only with gasoline, the emission of interest with respect to ozone formation potential is HC, but when alcohols are added to the fuel it is more accurate to speak of organics emissions, since that encompasses HC as well as other hydrogen-carbon-oxygen compounds that can play an important part in ozone formation. The quantitative effects of blend use on evaporative and exhaust organics emissions and ozone formation potential will be covered later in this section, but a qualitative description of those effects will be presented here.

The addition of either ethanol or methanol to gasoline increases the RVP of the resultant blend above the RVP of the alcohol or the gasoline alone. This is shown in Table 2-47, which summarizes the volatility effects of splash blending ethanol or methanol/cosolvent with gasoline. If nothing is done to the composition of the gasoline to compensate for this RVP increase, similar directional effects on diurnal, hot-soak, and exhaust emissions will occur as described previously for gasoline. In other words, evaporative and exhaust emissions increase with increasing RVP whether the RVP increase is due to butane addition or alcohol addition. Therefore, the determination of the effect of RVP on emissions will rely on the earlier analyses of evaporative and exhaust emissions from gasoline-fueled vehicles as a function of vapor pressure.

Table 2-47

Blend Volatility

	Volatility Increases with Splash Blending	
	10% Ethanol	5% Methanol +Cosolvent
RVP (psi)	0.5 - 1.0	2.0 - 2.5
$\%_{160\ F}$	10 - 15%	5 - 10%

A number of modifications to those analyses, however, are necessary to more precisely account for the presence of alcohol. One modification accounts for the difference in molecular weights of ethanol or methanol compared to evaporative hydrocarbons. This factor is added because the vapor pressure of a fuel determines (or is determined by) the number of moles (rather than the mass) of that fuel which will be in the vapor phase at a given temperature.

Another factor accounts for the increase in RVP which occurs with the commingling of gasoline-alcohol blends with gasoline-only fuels. Due to the non-linear nature of the RVP increase of alcohol addition, the commingling of a 9.0 psi gasoline with a 9.0 psi blend will result in a fuel with a greater RVP than 9.0 psi. This situation would occur in vehicle fuel tanks whenever vehicle owners switch from a gasoline to a blend or vice versa.

In addition to the above RVP-related factors which influence both diurnal and hot-soak emissions, blends tend to increase hot-soak losses from carbureted vehicles because of the change in the distillation curve with the addition of alcohol. Figure 2-17 shows how the presence of alcohol tends to increase the fraction of fuel evaporated at a given temperature in the 120 - 200°F range, which corresponds to fuel temperatures in the float bowl of a carburetor after the engine is shut off.

Exhaust emissions can be affected by the use of blends in two ways. In addition to the RVP-related increase mentioned above, the second factor, increased oxygen content, tends to decrease exhaust organics from many vehicles by causing enleanment of the fuel/air mixture.

Finally, besides the quantity of organics emitted from blend-fueled vehicles, the composition of those organics differs from gasoline-fueled vehicles, which affects the over-all photochemical reactivity associated with the emissions. For instance, evaporative emissions from methanol blend-fueled vehicles contain a certain fraction of methanol, which is less reactive than evaporative HC vapor. Each of these factors will be taken up in detail below, first for evaporative emissions and then for exhaust emissions.

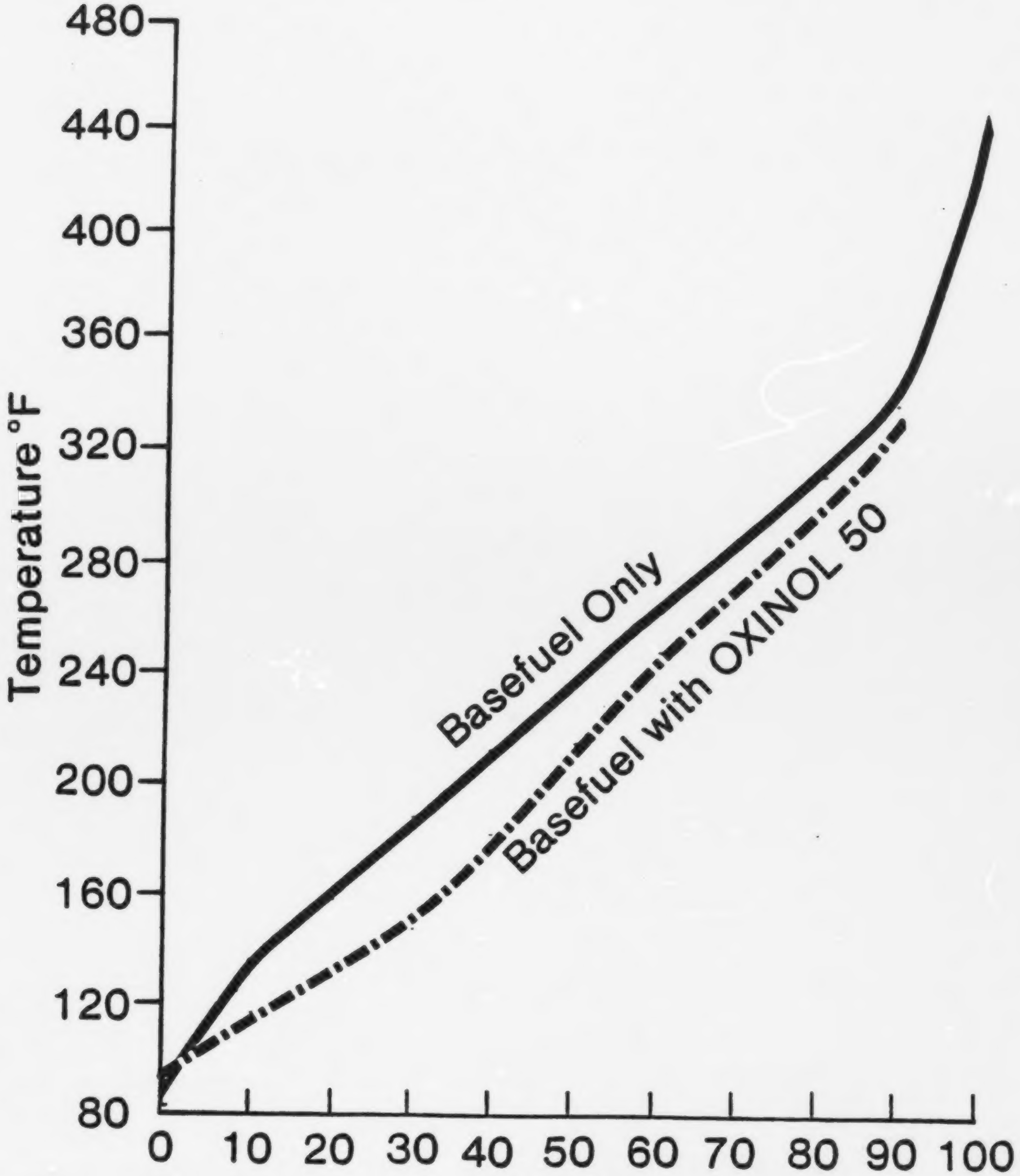
1. Effects of Alcohol Blends on Evaporative Emissions

a. Diurnal Emission Mass

As mentioned in the introduction to this chapter, the two major fuel factors that determine diurnal emissions are vapor pressure of the fuel itself and, for blends, commingling of the

Figure 2-17

Effects Of OXINOL™ 50 On Basefuel Volatility D-86 Results



blend with gasoline (which is just another factor affecting the vapor pressure of the final fuel). The analysis of the effect of fuel vapor pressure on diurnal emissions was presented for gasoline-only fuel earlier in this chapter, and that same model will be used here for blends. As shown there, this means that a blend with the same RVP as a gasoline yields the same number of molecules (moles) of vapor as the gasoline during a diurnal temperature rise.*

Note that this is number of moles of vapor rather than mass of vapor. When an adjustment is made to account for the lower molecular weight of ethanol (46) or methanol (32) relative to gasoline vapor (approximately 64), the diurnal emissions on a total organics mass basis are somewhat less than the gasoline. For ten percent ethanol blends the organics mass is about 96.7 percent as much as a gasoline of equal vapor pressure, while for methanol-cosolvent blends it is about 87 percent as much. These values assume a ten percent by mass average ethanol concentration in the ethanol blend vapor,[52,53,54,55,56] and a 15 percent methanol concentration in the methanol blend vapor.[57,58,59,60,61] For methanol blends, it is assumed that the cosolvent alcohol (TBA, ethanol, or other) is present in the vapor phase at a concentration low enough to be neglected.

The other factor, commingling, refers to the mixing of gasoline/alcohol blends with non-alcohol gasolines in vehicle fuel tanks whenever consumers switch from one fuel type to the other when refueling their vehicles at a service station. As shown in Figure 2-18, most of the RVP increase with alcohols occurs with the first one percent addition of alcohol. This information has been obtained in laboratory testing in which different proportions of gasoline and gasoline/alcohol blends are mixed to determine the resulting RVP and distillation.[61,62,63,64]

If a gas tank that is 20 percent full (i.e., has a 20 percent heel) of a gasoline/alcohol blend is refueled with gasoline of equal RVP but without alcohol, the RVP of the new mixture will be greater than either of the starting fuels because of the interaction of the alcohol with the new gasoline. It is not clear what an average heel is, but with a ten percent heel of methanol blend the RVP increase when filling the tank with gasoline would be about 1.4 psi. With a 50 percent heel the RVP increase would be about 2.0 psi.

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* Another difference between alcohol blends and gasoline is that the vapor pressure of alcohols decreases more drastically with lowered temperature than does the vapor pressure of gasoline. Therefore, for a blend and a gasoline with equal RVP (which is measured at 100°F), the blend would probably have a lower vapor pressure than the gasoline at a lower temperature. This factor has been neglected in this analysis since many of the cities considered have maximum diurnal temperatures close to 100°F.

For ethanol blends the effect is assumed to be about one third as great based on (a) the relative RVP boosts of ethanol and methanol blends and (b) the similar non-linearity of RVP vs. concentration of either blend, as shown in Figure 2-18. (i.e., the curves have similar shapes.) Therefore, in any area where blends and gasolines are available to consumers, some increase in average RVP and evaporative emissions due to commingling would be expected, but this effect is less for ethanol blends than methanol blends.

Some modeling has been done by ARCO to calculate what the increase in pool average RVP would be for various scenarios covering different blend market shares, degrees of customer loyalty to a particular retailer, and percentages of fuel remaining in the tank when it is to be refilled (heel). These results are shown in Figure 2-19 for the scenario with what ARCO considers to be a representative degree of customer loyalty. Since the RVP increases calculated with the ARCO model are fleet averages, the appropriate RVP increases to apply to blend-fueled vehicles are greater by a factor of roughly one/(market share). The resulting increases in RVP assuming brand loyalty, 20 percent full tank at refueling, and various market shares are shown in Table 2-48. A 0.2 psi commingling effect was chosen as being most representative of the current in-use situation, since gasohol dominates current alcohol blend use with local market shares between 10 and 40 percent.

One factor that has not been taken into account with respect to commingling is the fact that the vapor alcohol content with blends is not a linear function of the liquid alcohol content. This non-linear effect is shown in Figure 2-20 for a methanol/cosolvent blend (dashed line) and also for a methanol-only blend (solid line). If this were taken into account in the methanol blend calculations, it would tend to slightly decrease the organics mass associated with commingling (due to the lower molecular weight of methanol relative to gasoline vapor) and also slightly decrease the reactivity of commingled blend vapor due to the higher methanol content. Although this has not been directly factored into the calculations, it has been at least partially accounted for by assuming a methanol vapor content near the high end of the likely range (15 percent).*

Although no comparable vapor composition data are available for ethanol blends, it is reasonble to assume a more linear relationship between the vapor and liquid ethanol content than for methanol blends based on the less severe vapor

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* Note that the composition and concentration of the head space vapors has been shown to be highly dependent on head-space temperature.[51a]

Figure 2-18

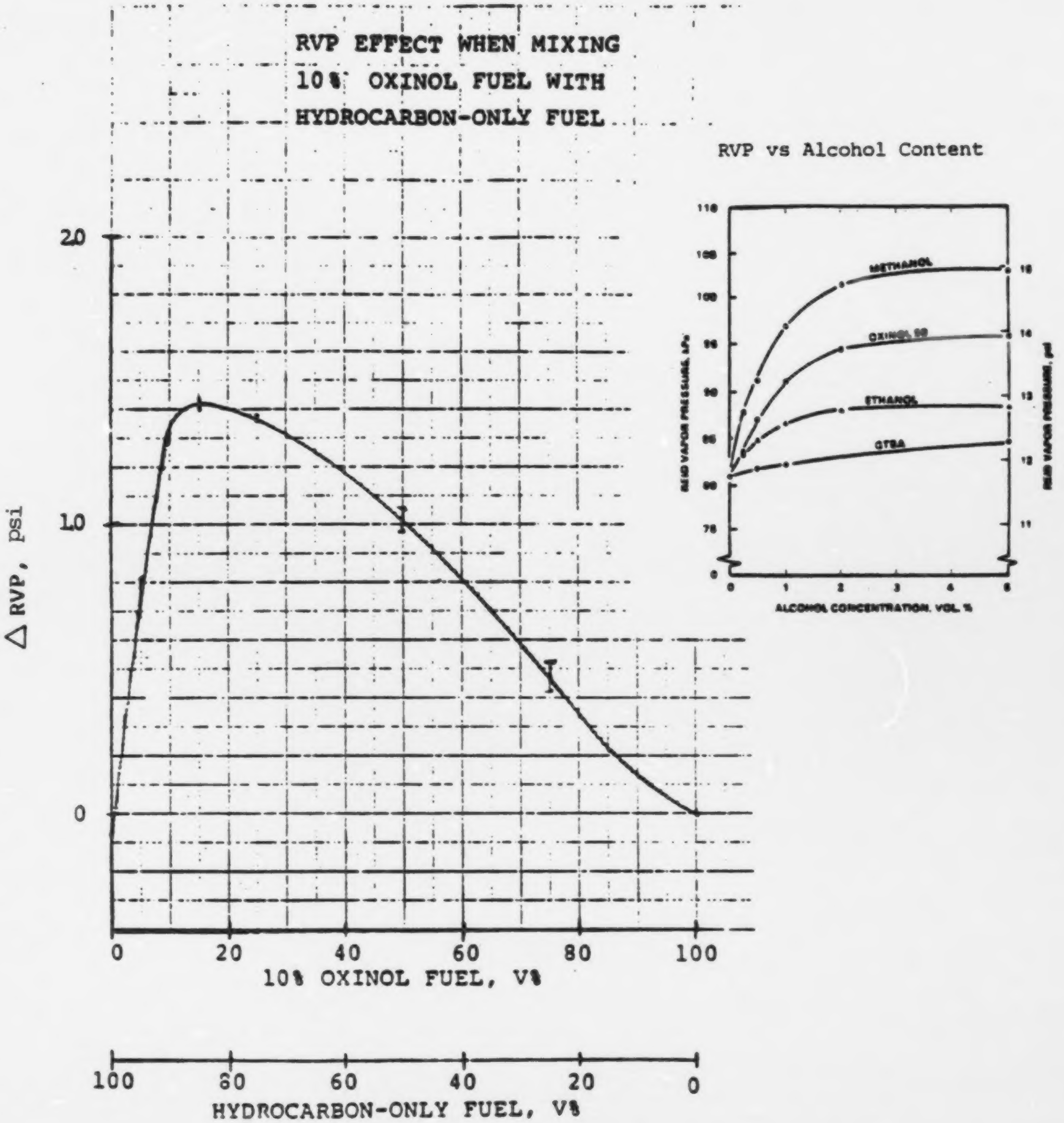

RVP EFFECT WHEN MIXING
10% OXINOL FUEL WITH
HYDROCARBON-ONLY FUEL
Δ RVP, psi
2.0
1.0
0
0
20
40
60
80
100
10% OXINOL FUEL, V%
100
80
60
40
20
0
HYDROCARBON-ONLY FUEL, V%
RVP vs Alcohol Content
REID VAPOR PRESSURE, kPa
110
105
100
95
90
85
80
75
0
REID VAPOR PRESSURE, psi
15
14
13
12
11
METHANOL
OXINOL 50
ETHANOL
GTBA
0
1
2
3
4
5
ALCOHOL CONCENTRATION, VOL %

Figure 2-19

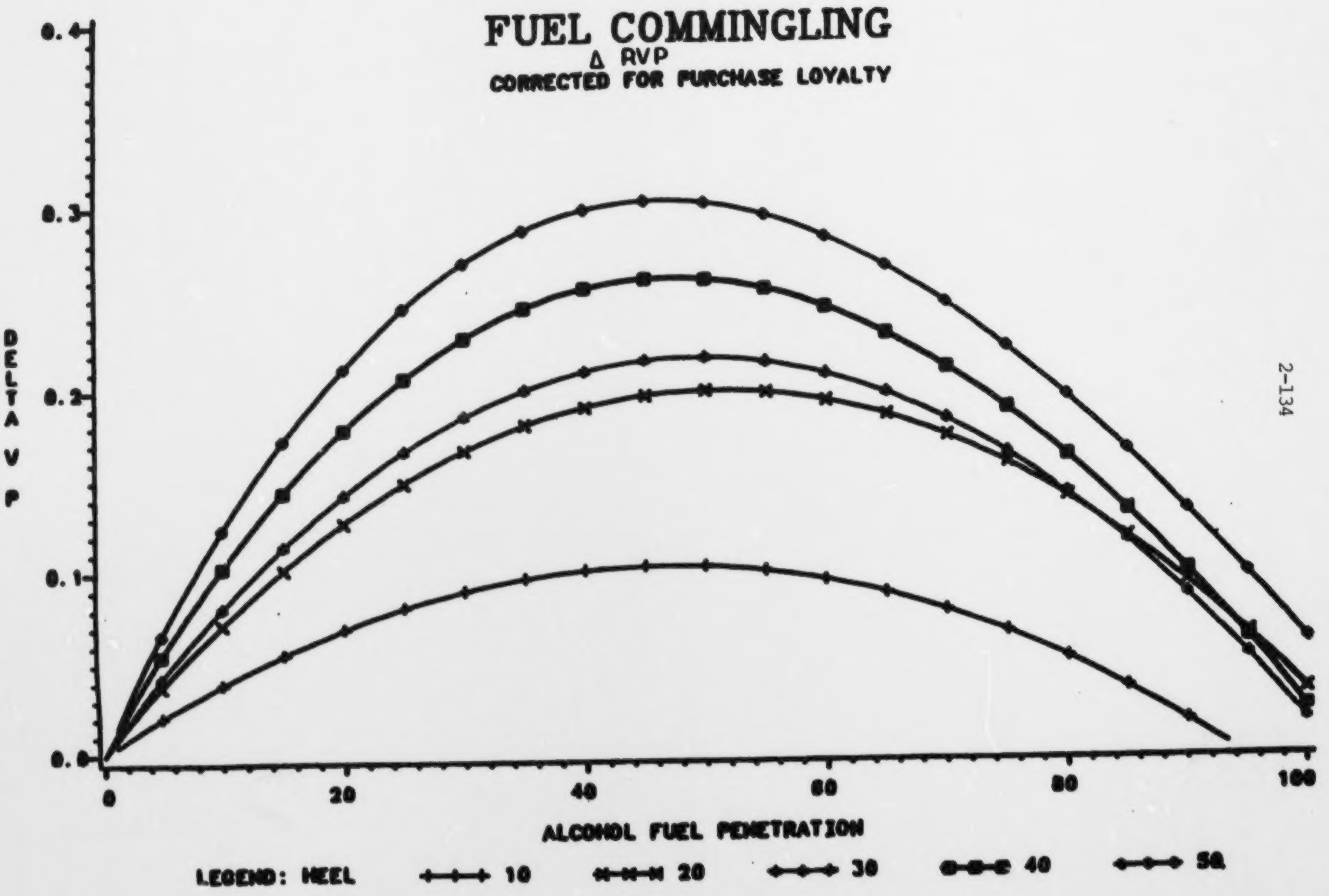

FUEL COMMINGLING
Δ RVP
CORRECTED FOR PURCHASE LOYALTY
DELTA V P
0.4
0.3
0.2
0.1
0.0
0
20
40
60
80
100
ALCOHOL FUEL PENETRATION
LEGEND: HEEL
10
20
30
40
50

Table 2-48

Commingling
Increases in Average RVP With Blend Use (psi)

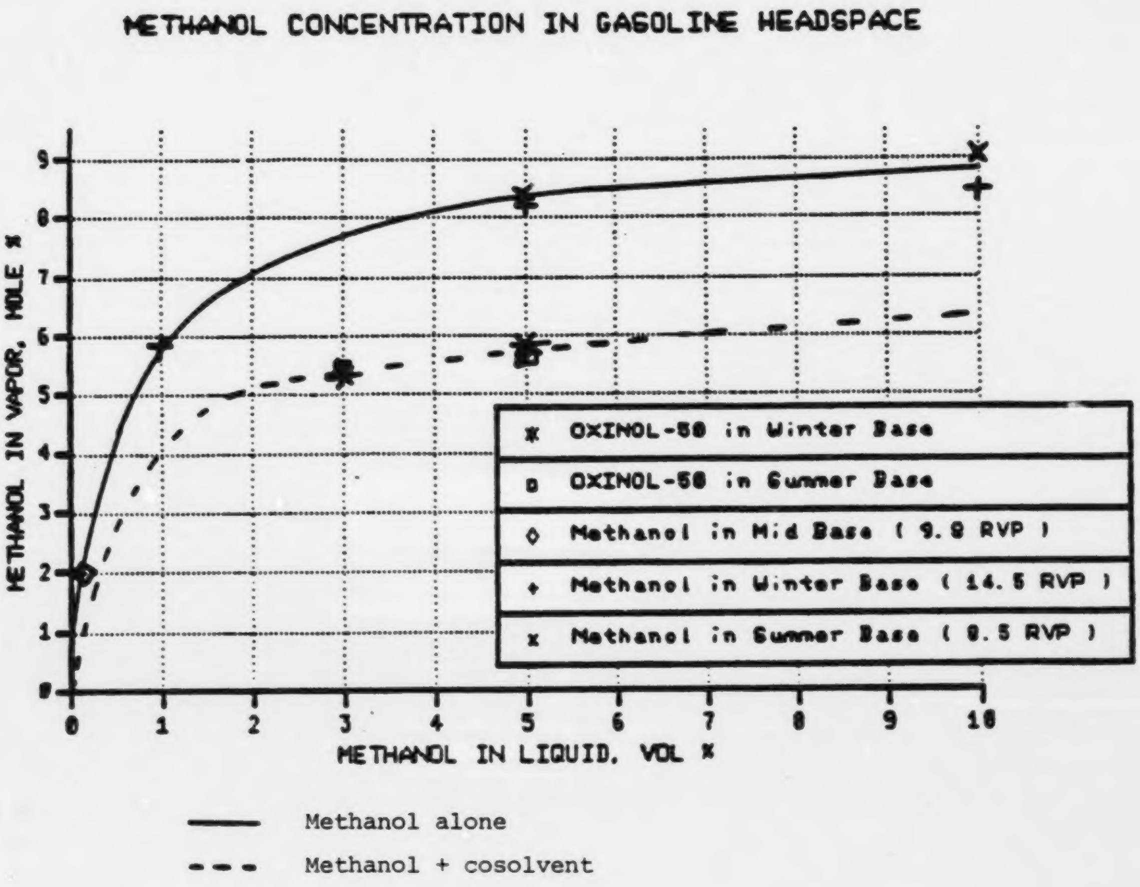
Market Share	Fleet Average Ethanol	Fleet Average Methanol	Blend-Fueled Vehicle Average[1] Ethanol[2]	Blend-Fueled Vehicle Average[1] Methanol
3%	--	0.025	--	0.8
10%	0.023	0.07	0.23	0.7
40%	0.06	0.19	0.16	0.5

---

[1] These numbers are simply back-calculated from the fleet averages. With a given (e.g., 3%) market share there is not necessarily just that (3%) of the fuel that is affected by commingling. Some fuel will not get commingled at all, and other fuel will get commingled more than once as more fuel is added to the tank with each new fill-up.

[2] Ethanol values are based on methanol blend values multiplied by 1/3 which is roughly the ratio of the RVP boost of ethanol addition (0.5-1.0 psi) to the RVP boost of methanol/cosolvent addition (2.0-2.5 psi).

Figure 2-20


METHANOL CONCENTRATION IN GASOLINE HEADSPACE
METHANOL IN VAPOR, MOLE %
0
1
2
3
4
5
6
7
8
9
METHANOL IN LIQUID, VOL %
0
1
2
3
4
5
6
7
8
9
10
OXINOL-50 in Winter Base
OXINOL-50 in Summer Base
Methanol in Mid Base (9.0 RVP)
Methanol in Winter Base (14.5 RVP)
Methanol in Summer Base (8.5 RVP)
Methanol alone
Methanol + cosolvent

pressure effects of ethanol. Also, the impact of any non-linearity would be less for ethanol than methanol since the molecular weight of ethanol is closer to that of gasoline vapor, and there are no reactivity benefits as there are with methanol.

b. Hot-Soak Emission Mass

For purposes of analysis hot-soak emissions can be considered to depend on two fuel factors. First is the RVP effect, which can be calculated exactly as it was for gasoline. The second factor affecting hot-soak emissions is the higher mid-range volatility, or distillation effect of blends if the blends have not had their distillation curves matched to gasoline. As examined earlier in this chapter in the mid-range volatility section, it is highly unlikely that the distillation curves of alcohol blends will match that of gasoline unless required by regulation to do so.

Hot-soak emissions usually contain a higher proportion of heavier hydrocarbons than diurnal emissions. The first reason for this is that higher temperatures are involved, which are able to vaporize higher molecular weight compounds. The second reason is that a charcoal canister is more effective in retaining the heavier compounds than the lighter ones, and some hot-soak losses, especially in carbureted vehicles, escape without going through the canister. For example, during a hot-soak gasoline may boil off at the carburetor in the vicinity of the engine resulting in emissions that resemble whole gasoline vapors.[51a]

The calculation of the effect of the higher RVP of an alcohol blend (if present) on hot-soak emissions is done exactly as with gasoline. The adjustment for the lower molecular weight of alcohol, which was done for diurnal emissions, is not applied. In the case of diurnal emissions, matched vapor pressure at some temperature implies equal moles of vapor generated at that temperature. For hot-soak emissions, however, a matched distillation curve means that equal volumes of fuel are evaporated at any given temperature in the ASTM D-86 test. For hot-soak emissions from carbureted vehicles, the temperature of interest is 160°F, since that is a typical fuel temperature in a carburetor float bowl during a hot-soak.

If the specific gravities (densities) of two fuels are the same, then equal volume percent evaporated also implies equal mass evaporated. The specific gravity of methanol is 0.796, while that of gasoline normally ranges from about 0.70 to 0.75. However, the fraction of gasoline that evaporates under hot-soak test conditions is composed of a higher proportion of lighter hydrocarbons with specific gravities around 0.65. This means that for equal volumes of fuel evaporated at a given temperature, a methanol blend would be expected to have a slightly greater mass evaporated than an HC-only fuel. Calculations that account for this factor indicate that it would result in roughly a three percent greater projected mass of hot-soak emissions from a methanol blend compared to a gasoline with matched $\%_{160}$. For ethanol blends this effect would be less, since the density of ethanol is closer to that of gasoline and the vapor generated from ethanol blends tends to have a smaller fraction of alcohol than that from methanol blends.

This is a very simplified view of a complex issue, since it does not take into account other variables such as the possible influence of the charcoal canister. Therefore, for purposes of this analysis it will be assumed that if the RVP and $\%_{160}$ of a blend are equal to that of a gasoline, the resulting hot-soak emissions will also be equal on a total mass basis (rather than a total moles basis as was the case for diurnal emissions).

Table 2-49 shows the net RVP effect on combined gram/mile diurnal and hot-soak organics emissions relative to gasoline assuming gram/mile values are calculated using the MOBILE3 equation:

Gram/mile = (diurnal grams + (3.05 * hot-soak grams))/31.1

The weighting of carbureted to fuel injected vehicle evaporative contributions for the 1990 and 2010 fleets are based on both relative VMT and relative gram/mile evaporative emissions. These weights depend on the RVP of the fuel, so a range of 9.0 - 11.7 psi was used. In 1990, at 9.0 psi the weighting is .68/.32 carbureted/F.I. total evaporative organics, and at 11.7 psi the weighting is .56/.44. In 2010, at 9.0 psi the weighting is .22/.78 carbureted/F.I. total evaporative organics, and at 11.7 psi the weighting is .14/.86.

The distillation effect on hot-soak emissions results from the greater mid-range volatility of blends shown in Figure 2-17. This effect could be neglected if the distillation curve of the blend were matched to gasoline, but due to the cost of such matching it is not likely to be done by refiners unless specifically required by regulation.

Hot-soak emissions from carbureted vehicles depend on the distillation curve of the fuel in addition to the RVP. Addition of methanol and/or ethanol to gasoline tends to increase the volatility of the fuel in the 120°F - 200°F temperature range as evidenced by the increased amount of fuel evaporated at these temperatures in an ASTM D86 distillation test. This effect was shown in Figure 2-17 with typical graphs of temperature versus percent evaporated for a gasoline and a

Table 2-49

Projected RVP Impact On Evaporative Organics Mass From Blend-Fueled Vehicles*

	Relative to Gasoline Matched RVP	1.0 psi Margin
10% Ethanol Blend		
Carbureted	-1.0-1.6%	+24-55%
Fuel Injected	-1.6-2.0%	+53-76%
1990 Mix	-1.2-1.8%	+33-64%
2010 Mix	-1.4-1.9%	+46-73%
Methanol/Cosolvent Blend		
Carbureted	-3.5-5.4%	+21-47%
Fuel Injected	-5.4-6.7%	+47-65%
1990 Mix	-4.1-6.0%	+29-55%
2010 Mix	-4.9-6.5%	+41-63%

---

* This includes the RVP effect on both diurnal and hot-soak emissions. The minimums correspond to current certification fuel RVP (9.0 psi) and the maximums to current in-use RVP (averaging near 11.5 psi for ASTM Class C).

matched RVP methanol/cosolvent blend. Ethanol blends produce a similar "knee" in the curve as methanol blends, but the knee is offset toward higher temperatures due to the higher boiling point of ethanol.

This temperature range corresponds to the temperatures experienced by fuel in hot-soak situations during the SHED hot-soak test. For instance, on carbureted vehicles, 160°F is a typical temperature for fuel in the carburetor float bowl during a hot-soak. On fuel injected vehicles, for which the fuel tank is the main source of hot-soak losses, the fuel temperature in the tank may range up to 120°F depending on how the tank is situated relative to the exhaust system and how much cooling it received during the prior driving.

As shown in Table 2-50 the percent evaporated at 160°F ($\%_{160}$) in the ASTM D86 distillation test increases by roughly 12 percent for a matched RVP ten percent ethanol blend and five percent for a matched RVP methanol/cosolvent blend relative to gasoline.[62,65,66] (e.g., for ethanol, an increase from 25 percent evaporated to about 37 percent evaporated at 160°F.) Since these values are based on experimental data, it can be assumed that they account for whatever butane removal would be needed to achieve equal RVP, as well as the effect of that butane removal on $\%_{160}$. The amount of change in $\%_{160}$ with blends is dependent on the individual base gasoline composition as well as the type and amount of alcohol used.

The effect of commingling on $\%_{160}$ is negligible, since the effect of alcohol on $\%_{160}$ is a nearly linear function of the amount of alcohol, whereas the RVP effect is very non-linear.

The effect of a change in $\%_{160}$, as separate from any RVP change, has been investigated by EPA by testing about thirty 2-gram vehicles with gasolines having an identical RVP (10.9 psi) but differing $\%_{160}$ (23 percent for one fuel and 39 percent for the other).[44] These data indicate an increase in hot-soak emissions relative to gasoline for vehicles with carburetors, but no significant change for those with fuel injection. A more detailed description of this analysis was presented earlier in this chapter. This analysis has been applied to blends and the calculated effects of the increased $\%_{160}$ on hot-soak emissions are shown in Table 2-50.

In the case of a blend meeting a 1.0 psi higher RVP limit than gasoline, the same calculations apply, except for two adjustments. First, with a 1.0 psi margin for the blend there is a greater difference in $\%_{160}$ relative to gasoline than in the matched RVP case. The first part ("Full Effect") of Table 2-51 shows the increases in $\%_{160}$ and the corresponding increases in evaporative emissions that would be expected with blends that have an RVP 1.0 psi greater than gasolines.

Table 2-50

Distillation Effect On Mass Hot-Soak Losses (Relative to Gasoline of Equal RVP)

Blend	Delta $\%_{160}$	Delta Hot-Soak[1] Carb.	Delta Hot-Soak[1] F. Inj.	Delta g/Mile[2] Carb.	Delta g/Mile[2] F. Inj.
Ethanol	12%	+8.3-21%	+0%	+4.8-11.7%	+0%
Methanol	5%	+4.4- 8%	+0%	+2.6- 4.5%	+0%

---

[1] Based on analysis of ATL test data in Chapter 2. The low number is based on an additive analysis, and the high number is based on a multiplicative analysis.

[2] The hot-soak percentage is weighted three times the diurnal percentage, and is also weighted by MOBILE3 hot-soak versus diurnal g/test in calculating percent changes in g/mile.

Table 2-51

Distillation Effect On Mass Hot-Soak Losses (Relative to Gasoline at 1.0 psi Lower RVP)

	Delta	Delta Hot-Soak[1]		Delta g/Mile[2]	
Blend	$\%_{160}$	Carb.	F. Inj.	Carb.	F. Inj.
Full Effect:					
Ethanol	15%	+12.8-27%	+0%	+7.2-15%	+0%
Methanol	7%	+6.0-11.8%	+0%	+3.5-6.6%	+0%
Minus $4\%_{160}$ Included in RVP Effect:					
Ethanol	11%	+8.9-19%	+0%	+5.1-10.8%	+0%
Methanol	3%	+2.6- 5%	+0%	+1.5- 2.7%	+0%
(splash methanol, 2.3 psi above base)	10%	+8.1-17%	+0%	+4.7-9.3%	+0%

---

[1] Based on analysis of ATL test data in Chapter 2. The low number is based on an additive analysis, and the high number is based on a multiplicative analysis.

[2] The hot-soak percentage is weighted three times the diurnal percentage, and is also weighted by MOBILE3 hot-soak versus diurnal g/test in calculating percent changes in g/mile.

The second adjustment arises from the fact that the high RVP test fuels used in EPA's emission factor program not only had a higher RVP than the low RVP fuel, but also had a greater $\%_{160}$. This effect on hot soak emissions is automatically included when the 1.0 psi RVP difference is accounted for. Therefore, a portion of the 'Full Effect' increases in $\%_{160}$ should be removed.

According to the fuel specifications for the gasolines used in the Emission Factor (EF) work (which was the basis for the analysis of vapor pressure effects on evaporative emissions) the 2.7 psi difference in RVP between the lowest and highest RVP test fuels was accompanied by a difference in $\%_{160}$ of about ten percent. Therefore, a 1.0 psi increase in RVP is assumed to correspond to a four percent increase in $\%_{160}$ in the gasoline. The subtraction of this $4\%_{160}$ is shown in the second part of Table 2-51. For comparison the values corresponding to a splash methanol blend are also shown, although this is not an option that is being considered.

c. Reactivity of Evaporative Emissions

This issue relates to the fact that a portion of the evaporative emissions from gasoline/alcohol blends consists of alcohol, and various studies conducted by EPA, CARB, and others indicate that, on a mole carbon basis, methanol is less photochemically reactive than typical hydrocarbon vapors. In other words, when exposed to sunlight, methanol's carbon atom reacts to form ozone more slowly than typical hydrocarbons. The reactivity of ethanol, however, is expected to be greater than methanol and on the same order as hydrocarbons such as butane or toluene based on its rate constant for reaction with OH radicals.[67] The subject of hydrocarbon reactivity is covered in more detail in Appendix 3-A.

The two factors involved in this issue are: (1) what portion of the evaporative emissions consists of methanol, and (2) how much less reactive is methanol relative to the hydrocarbons it displaces. The first factor was covered above in the section on blend RVP effects. As already mentioned, based on available data for methanol/cosolvent blends a methanol content of 15 percent of the total vapor mass (HC plus alcohol) is assumed in both diurnal and hot-soak emissions. For ethanol blends an ethanol content of ten percent is assumed.

EPA photochemical modeling and smog chamber data for single day episodes indicate that methanol is about two percent - 43 percent as reactive as non-methane hydrocarbons on a carbon-for-carbon basis.[68,69] Therefore, the much lower reactivity of the methanol in the vapor needs to be accounted for in determining the effect on ozone forming potential of methanol blends. Table 2-52 gives a comparison of reactivity with gasoline-only evaporative vapor and with vapor containing

Table 2-52

Reactivity of Blend Evaporative Organics

Component:	Gasoline	Ethanol	Methanol
Relative reactivity per Carbon atom	1.00	1.00	0.02-0.43
Relative Carbon atoms per gram of component	1.00	0.62	0.44
Blend vapor composition (mass %)	100% HC	90% HC 10% EtOH	85% HC 15% MeOH
Relative reactivity per gram of blend evaporative organics	1.00	0.962	0.851-0.878

either ten percent ethanol or 15 percent methanol by mass. The reactivity per gram of ethanol blend vapor is slightly lower than gasoline (by four percent), because although an equal reactivity per carbon atom is assumed, ethanol has fewer carbon atoms per gram than gasoline. Methanol blend vapor is estimated to be about 12 percent - 15 percent less reactive than gasoline vapor.

A more recent multi-day study conducted at the Riverside smog chamber by CARB indicates that methanol may react more completely given a second day of irradiation, and if this is validated in subsequent modeling, it could negate at least some of the above reactivity benefits of methanol substitution in multi-day ozone situations.[70] However, the extrapolation of smog chamber results to real world situations is very complex and more study is necessary before it is clear how this smog chamber work affects our current understanding of methanol's reactivity in the atmosphere.

2. Effect of Alcohol Blends on Exhaust Emissions

a. Exhaust Emission Mass

The use of gasoline-alcohol blends can affect the quantity of exhaust organics in two ways. First, the presence of oxygen in the fuel tends to alter the fuel/air mixture, and second the RVP itself affects exhaust HC.

Regarding the first factor, neat methanol has an oxygen content of 50 percent by weight while that of ethanol is 35 percent. When blended with gasoline per existing EPA waivers the oxygen content of all blends is limited to 3.7 percent (3.5 percent for Oxinol). Oxygen content can be an important factor in exhaust emissions from vehicles with open-loop (non-feedback) control systems because the presence of oxygen in the fuel makes the air/fuel mixture leaner than if the fuel consisted only of hydrocarbons. If a carburetor is operating rich on gasoline, with the excess HC and CO emissions that result from rich operation, and then an oxygenated fuel is used instead of gasoline, the mixture will become leaner and the excess HC and CO emissions would be expected to decrease.

As summarized in Table 2-53, a large gasohol study showed a substantial reduction in average exhaust HC for open-loop vehicles using ethanol splash blends compared to base gasolines of 9.0 and 10.0 psi RVP.[65] With closed-loop vehicles the results were sufficiently mixed that no significant change in average HC could be attributed to the addition of the ethanol.

Table 2-53

Exhaust HC Effects of Blends

Study	Fuels	Blend Results
EPA-MSED[65] (ethanol)	a) Indolene b) (a)+10% ethanol c) 10 psi gasoline d) (c)+10% ethanol e) (d) volatility matched with (c)	15-20% reduction in exhaust HC with splash blends in open-loop vehicles. No significant change for closed-loop vehicles.
DuPont [13] ARCO [71], CRC [21]	Indolene, commercial gasolines, matched volatility methanol blends	7.1-26.4% reductions exhaust HC in open-loop vehicles. 0-5% reductions in exhaust HC in closed-loop vehicles.
EPA [62]	a) Indolene, b) commercial gasoline c) Oxinol blend volatility matched with (b)	6% increase in exhaust HC in open-loop vehicles. No change in exhaust HC in closed-loop vehicles.

Regarding methanol blends, test programs conducted by DuPont,[13] ARCO,[71] and the Coordinating Research Council (CRC),[21] also showed substantial reductions in average exhaust HC relative to gasoline for open-loop (pre-1981) vehicles using a five percent methanol/2.5-5 percent cosolvent blend. However, a slight decrease in HC was found for closed-loop (post-1981) vehicles. Many of the ARCO vehicles had high HC and CO emissions when tested with gasoline, indicating that they were running richer than optimum, and thus probably showed a greater benefit from the leaning effect of the blend fuel than if the calibration had not been rich. Each study used 8 to 11 vehicles, approximately half of which were open-loop and half closed-loop. The study averages for closed-loop cars ranged from a decrease of 18 percent to an increase of eight percent. The range of results for individual vehicles is much greater, with many showing decreases while others show increases.

Another relevant study was conducted by EPA using 23 in-use ("Emission Factor") vehicles.[62] This study showed an average increase of exhaust hydrocarbons of about six percent relative to gasoline for the eight open-loop vehicles tested with a methanol/TBA blend of similar RVP, and no change in average hydrocarbons for the 15 closed-loop vehicles. EPA test experience has shown that consistency in test sequence/ preconditioning of the evaporative control system is an important factor that could lead to discrepancies in results of different studies.

A second factor affecting exhaust HC is fuel volatility. As discussed earlier in this chapter, there is a small but statistically significant and measureable increase in exhaust HC with increasing RVP. In the gasohol study mentioned above, the 10 psi base gasoline had 19 percent greater exhaust HC than the 9.0 psi gasoline, and the 10.6 psi blend had 26 percent greater HC than the 9.8 psi blend. However, for some reason the volatility adjusted 10.0 psi blend yielded HC emissions greater than the 10.6 psi splash blend and equivalent to the 10.0 psi base gasoline. As mentioned above, there may have been canister preconditioning differences that influenced these results.

Based on analysis of the far larger gasoline data base of the EPA Emission Factor (EF) program, the increase in exhaust HC with increasing RVP is approximately 0.04 g/mile (four percent) per psi. For blends that have not been volatility adjusted to be equal to gasoline, the increased exhaust HC from the greater RVP would tend to partially counteract the leaning-out effect described above. Also, the degree of blend volatility control would determine how much this factor affects exhaust HC. If blend RVP is controlled to the same level as gasoline, then this factor would not be expected to affect exhaust HC.

Regarding aldehydes, one study by CRC for DOE using various methanol blends measured only total aldehydes, and the results were so scattered that no particular effect of blend use on total aldehydes could be determined. However, an EPA study measured HCHO specifically and found it to be two percent of exhaust HC with a five percent methanol/five percent TBA blend (similar to Oxinol) versus one percent with gasoline.[59] Since the reactivity of formaldehyde is approximately three times that of exhaust hydrocarbons, a one percent increase in the formaldehyde concentration would increase the exhaust reactivity by roughly two percent.

However, this effect is balanced by a corresponding increase in exhaust methanol concentration with use of a methanol blend. Various studies have found this concentration to range from almost zero up to as high as eight mass percent, but a typical value is two to three percent. Since the reactivity of methanol is much less than exhaust hydrocarbons, this concentration of methanol would decrease the exhaust reactivity roughly counterbalancing the increase in reactivity from the increased formaldehyde concentration. Therefore, as with ethanol blends, the exhaust reactivity of methanol blends is assumed to be the same as gasoline.

3. Combined Evaporative and Exhaust Effects of Alcohol Blend Usage on Ozone

As shown in Tables 2-54 and 2-55, for 1990 and 2010 fleet mixes respectively, the estimated exhaust organics and ozone benefits from blend use are nearly exactly offset by the increases in evaporative organics and ozone potential in the matched RVP scenario for both ethanol and methanol blends. However, in the 1.0 psi margin scenario, increases of about one percent - 13 percent in 1990 and about one percent - ten percent in 2010 in fleet ozone potential relative to a gasoline-only case are predicted, depending on blend market penetration.

Tables 2-56 and 2-57 provide a detailed breakdown of all the contributing factors to the final results in Tables 2-54 and 2-55. Tables 2-56 and 2-57 summarize the estimated exhaust and evaporative effects of ethanol and methanol blend use on average organic emissions, adjusted for reactivity, from the portion of the light duty vehicle fleet using those blends. Note that the commingling effects attributable to blend-fueled vehicles depend on the market share of the blend, so the commingling values in Tables 2-56 and 2-57 were back-calculated from fleet average values by dividing the fleet values by the market share.

An analysis of these data indicates that some exhaust hydrocarbon benefits are expected with open-loop vehicles using the waived methanol or ethanol blends at an RVP equal to gasoline, but much smaller exhaust hydrocarbon changes are expected for closed-loop vehicles.[72] Likely exhaust HC reductions were determined to range from 7.2-11.4 percent for open loop and 0-4.7 percent for closed loop vehicles. A linear regression of the emission data versus fuel oxygen content yielded an average reduction of 7.4 percent for open-loop vehicles and 4.6 percent for closed-loop vehicles. Weighting these two factors by an estimated total exhaust HC contribution from open versus closed-loop vehicles yields a 7.0 percent average reduction in exhaust HC for blend-fueled vehicles. This split was estimated by using MOBILE3 with RACT I/M and comparing the total tons of exhaust HC from pre-1981 and 1981+ light-duty vehicles in the year 1990.

For the scenario with a 1.0 psi RVP blend margin, the RVP effect on exhaust organics (0.04 g/mile per psi) needs to be added to the above oxygen effect. The result of this is a four percent greater level of exhaust organics than in the RVP matched scenario, or a net three percent reduction due to alcohol usage.

b. Reactivity of Exhaust Organics

This issue concerns the fact that a portion of the exhaust emissions from gasoline and blend fueled vehicles consists of formaldehyde (HCHO), which is approximately three times as photochemically reactive as typical exhaust hydrocarbons. Exhaust emission data from blend fueled vehicles have been examined to determine if such emissions contain a different proportion of formaldehyde than exhaust emissions from the same vehicles fueled with gasoline.

Two studies with 10 percent ethanol blends measured total aldehydes and the results indicated that the aldehyde proportion of total organics could increase slightly on average for catalyst equipped vehicles.[52,73] These are of limited applicability since HCHO was not specifically measured and one study was conducted at high altitude. However, another study measured HCHO specifically using two 10 percent ethanol blends in two oxidation catalyst vehicles and one three-way catalyst vehicle.[74] This study found that the HCHO percent of total HC remained essentially unchanged when switching from the base gasolines to the ethanol blends. Therefore, no adjustment for exhaust reactivity has been used in calculating the ozone impact of ethanol blends.

Regarding methanol blends, there are two counteracting factors affecting exhaust reactivity. First, there is an increase in percentage of formaldehyde, and second, there is a small amount of unburned methanol in the exhaust organics.

Table 2-54

Projected Fleet Ozone Impact of Blends in 1990
% Change in Total (Exhaust + Evap) LDV Ozone Formation Potential From a Gasoline-only Baseline[1]

	3% Share		10% Share		40% Share	
	RVP Matched	+ 1 psi Margin	RVP Matched	+1 psi Margin	RVP Matched	+1 psi Margin
Ethanol Blends						
TOTAL FLEET EVAP OZONE EFFECT	-	-	+0.16-.87	+1.6-3.5	+.37-2.8	+6.2-13.3%
TOTAL FLEET EXHAUST OZONE EFFECT	-	-	-0.36%	-0.14%	-1.4%	-0.55%
TOTAL FLEET OZONE EFFECT	-	-	-0.20-(+).51	+1.5-3.4	-1.0-(+)1.4	+5.6-12.6%
Methanol Blends						
TOTAL FLEET EVAP OZONE EFFECT	-.01-(+).35	+.37-1.1	-.17-(+)0.84	+1.1-3.2	-1.7-(+).96	+3.3-10.3%
TOTAL FLEET EXHAUST OZONE EFFECT	-0.11%	-0.04%	-0.36%	-0.14%	-1.4%	-0.55%
TOTAL FLEET OZONE EFFECT	-0.12-(+).24	+.33-1.1	-.53-(+).48	+0.9-3.0	-3.1-(-)0.4	+2.7-9.7%

---

[1] Based on actual mass of HC plus alcohol rather than FID measurement. Evap/exhaust organics contribution has been weighted by .452/.548.

Table 2-55

Projected Fleet Ozone Impact of Blends in 2010
% Change in Total (Exhaust + Evap) LDV Ozone Formation Potential
From a Gasoline-only Baseline[1]

	3% Share		10% Share		40% Share	
	RVP Matched	+1 psi Margin	RVP Matched	+1 psi Margin	RVP Matched	+1 psi Margin
Ethanol Blends						
TOTAL FLEET EVAP OZONE EFFECT	-	-	+.08 -.25	+1.4-2.3	+.02-.49	+5.6-9.1%
TOTAL FLEET EXHAUST OZONE EFFECT	-	-	-0.36%	-0.08%	-1.5%	-0.34%
TOTAL FLEET OZONE EFFECT	-	-	-0.28-(-).11	+1.3-2.2	-1.5-(-)1.0	+5.3-8.8%
Methanol Blends						
TOTAL FLEET EVAP OZONE EFFECT	+0.06-.22	+.41-.77	+.04-.51	+1.2-2.3	-.79-(+).39	+3.9-7.6%
TOTAL FLEET EXHAUST OZONE EFFECT	-0.11%	-0.03%	-0.36%	-0.08%	-1.5%	-0.34%
TOTAL FLEET OZONE EFFECT	-.05-(+).11	+.38-.74	-.32-(+).15	+1.1-2.2	-2.3-(-)1.1	+3.6-7.4%

---

[1] Based on actual mass of HC plus alcohol rather than FID measurement. Evap/exhaust organics contribution has been weighted by .301/.699.

Table 2-56

Projected Organics and Ozone Impact of 10% Ethanol Blends On Blend Fueled Vehicles

	Total Organics with 1.0 psi RVP Margin[1]			
EVAPORATIVE	Carbureted	Fuel Injected	1990 Mix[2]	2010 Mix[3]
RVP	+24.0-55.0%	+53.0-76.0%	+33.0-64.0%	+46.4-72.9%
Distillation	+6.1-16.8%	+0%	+4.4-10.1%	+1.6- 2.9%
Commingling[4]	+2.5- 8.8%	+7.4-11.9%	+4.1-10.2%	+6.3-11.5%
Total Evap Mass Effect			+41.5-84.3%	+54.3-87.3%
Evap Ozone Effect (Reactivity Factor = 0.962)			+36.1-77.3%	+46.4-77.0%
EXHAUST	Open Loop	Closed Loop	1990 Mix[5]	2010 Mix[6]
Exhaust Mass Effect	-3.4%[7]	-0.6%	-2.5%	-1.2%
Exhaust Ozone Effect (Reactivity Factor = 1.000)			-2.5%	-1.2%
TOTAL OZONE EFFECT[8]			+14.9-33.6%	+13.1-22.3%

	Total Organics with Meeting Gasoline RVP Limit[1]			
EVAPORATIVE	Carbureted	Fuel Injected	1990 Mix[2]	2010 Mix[3]
RVP	-1.0- 1.6%	-1.6- 2.0%	-1.2- 1.8%	-1.4- 1.9%
Distillation	+6.5-17.9%	+0%	+4.7-15.5%	+1.7- 3.0%
Commingling[4]	+2.5- 8.8%	+7.4-11.9%	+4.1-10.2%	+6.3-11.5%
Total Evap Mass Effect			+7.6-23.9%	+6.6-12.6%
Evap Ozone Effect (Reactivity Factor = 0.962)			+3.5-19.2%	+2.5- 8.3%
EXHAUST	Open Loop	Closed Loop	1990 Mix[5]	2010 Mix[6]
Exhaust Mass Effect	-7.4%[7]	-4.6%	-6.5%	-5.2%
Exhaust Ozone Effect (Reactivity Factor = 1.000)			-6.5%	-5.2%
TOTAL OZONE EFFECT[8]			-2.0-(+)5.1%	-2.9-(-)1.1%

---

[1] Based on actual mass of HC plus ethanol rather than FID measurement.

[2] Weights .68/.32 (@ 9.0 psi) to .56/.44 (@ 11.68 psi) Carb/FI total evap; .72/.28 (@ 9.0 psi) to .60/.40 (@11.68 psi) Carb/FI hot-soak evap; includes VMT & g/mile weights.

[3] Weights .22/.78 (@ 9.0 psi) to .14/.86 (@ 11.68 psi) Carb/FI total evap; .26/.74 (@ 9.0 psi) to .17/.83 (@11.68 psi) Carb/FI hot-soak evap; includes VMT & g/mile weights.

[4] Assumes a 10% alcohol blend market penetration.

[5] Based on a .666/.334 OL/CL exhaust weighting including VMT & g/mile.

[6] Based on a .200/.800 OL/CL exhaust weighting including VMT & g/mile.

[7] Exhaust benefit lower with higher RVP than lower RVP fuels due to increase in exhaust HC with higher RVP. (A 1.0 psi increase in RVP increases exhaust HC by about 4%.)

[8] Weights .452/.548 evap/exhaust in 1990, .301/.699 evap/exhaust in 2010.

Table 2-57

Projected Organics and Ozone Impact of Methanol Blends On Blend Fueled Vehicles

	Total Organics with 1.0 psi RVP Margin[1]			
EVAPORATIVE	Carbureted	Fuel Injected	1990 Mix[2]	2010 Mix[3]
RVP	+21.0-47.0%	+47.0-65.0%	+29.0-55.0%	+41.4-62.8%
Distillation	+1.4- 4.3%	+0%	+1.0- 2.6%	+0.4- 0.7%
Commingling[4]	+10.9-34.0%	+27.0-39.0%	+15.4-36.0%	+23.5-38.3%
Total Evap Mass Effect			+45.4-93.6%	+65.3-101.8%
Evap Ozone Effect (Reactivity Factor=0.851-0.878)			+23.7-70.0%	+40.7-77.2%
EXHAUST	Open Loop	Closed Loop	1990 Mix[5]	2010 Mix[6]
Exhaust Mass Effect	-3.4%[7]	-0.6%	-2.5%	-1.2%
Exhaust Ozone Effect (Reactivity Factor = 1.000)			-2.5%	-1.2%
TOTAL OZONE EFFECT[8]			+ 9.3-30.3%	+11.4-22.4%

	Total Organics with Meeting Gasoline RVP Limit[1]			
EVAPORATIVE	Carbureted	Fuel Injected	1990 Mix[2]	2010 Mix[3]
RVP	-3.5- 5.4%	-5.4- 6.7%	-4.1- 6.0%	-4.9- 6.5%
Distillation	+2.5- 8.3%	+0%	+1.8- 5.0%	+0.6- 1.4%
Commingling[4]	+10.9-34.0%	+27.0-39.0%	+15.4-36.0%	+23.5-38.3%
Total Evap Mass Effect			+13.1-35.0%	+19.2-33.2%
Evap Ozone Effect (Reactivity Factor=0.851-0.878)			-3.8-(+)18.5%	+1.4-16.9%
EXHAUST	Open Loop	Closed Loop	1990 Mix[5]	2010 Mix[6]
Exhaust Mass Effect	-7.4%[7]	-4.6%	-6.5%	-5.2%
Exhaust Ozone Effect (Reactivity Factor = 1.000)			-6.5%	-5.2%
TOTAL OZONE EFFECT[8]			-5.3-(+)4.8%	-3.2-(+)1.5%

---

[1] Based on actual mass of HC plus methanol rather than FID measurement.

[2] Weights .68/.32 (@ 9.0 psi) to .56/.44 (@ 11.68 psi) Carb/FI total evap; .72/.28 (@ 9.0 psi) to .60/.40 (@11.68 psi) Carb/FI hot-soak evap; includes VMT & g/mile weights.

[3] Weights .22/.78 (@ 9.0 psi) to .14/.86 (@ 11.68 psi) Carb/FI total evap; .26/.74 (@ 9.0 psi) to .17/.83 (@11.68 psi) Carb/FI hot-soak evap; includes VMT & g/mile weights.

[4] Assumes a 10% alcohol blend market penetration.

[5] Based on a .666/.334 OL/CL exhaust weighting including VMT & g/mile.

[6] Based on a .200/.800 OL/CL exhaust weighting including VMT & g/mile.

[7] Exhaust benefit lower with higher RVP than lower RVP fuels due to increase in exhaust HC with higher RVP. (A 1.0 psi increase in RVP increases exhaust HC by about 4%.)

[8] .452/.548 evap/exhaust weighting in 1990, .301/.699 evap/exhaust weighting in 2010.

Since carbureted and fuel-injected vehicles have different evaporative emission characteristics, a 1990 and 2010 fleet mix of these two technologies was used to weight the evaporative effects, including the relative vehicle-miles-traveled (VMT) and gram/mile evaporative emissions of the two vehicle types. Similarly, a 1990 and 2010 light duty fleet mix of open-loop and closed-loop control systems was used to weight the exhaust effects. As above, the weighting accounted for both VMT and exhaust g/mile emissions, thus weighting the contributions by total mass contribution. The relative VMT and g/mile emissions were taken from MOBILE3. As a rough estimate of the open-loop/closed-loop ratio, 1981 and later vehicles were considered closed-loop, and pre-1981 vehicles were considered open-loop. The resulting ratio is 0.666 open-loop/0.334 closed-loop in 1990, and 0.200 open-loop/ 0.800 closed-loop in 2010. If light-duty trucks were excluded from the analysis, open-loop vehicles would account for a smaller fraction of the total.

Considering the relative contributions of exhaust and evaporative emissions, these factors translate into a change in average blend-fueled vehicle total organics emissions, adjusted for reactivity, of -5.3 percent (methanol blend, matched RVP, minimum) up to +33.6 percent (ethanol blend, 1.0 psi margin, maximum) in 1990. Considering the relative contributions of exhaust and evaporative emissions, in 2010 these factors translate into a change in average blend-fueled vehicle total organics emissions of -3.2 percent (methanol blend, matched RVP, minimum) up to +22.4 percent (methanol blend, 1.0 psi margin, maximum).

C. Gasoline Distribution System

While this analysis focuses primarily on the reductions in hydrocarbon emissions (particularly evaporative emissions) from motor vehicles, the regulation of in-use fuel volatility will also have an impact on emissions from gasoline-related stationary sources. As the levels of evaporated hydrocarbons emitted during the storage, handling, and distribution of gasoline are a function of true vapor pressure (which in turn is dependent on the RVP of the fuel), the control of in-use fuel RVP will also affect the level of emissions from these sources. Of course, the other primary aspects of this proposal (changes to certification test fuel volatility and test procedures) will have no impact on these sources of emissions, since they involve only changes in the design of new vehicles.

This section discusses the effect of in-use RVP control on two basic sources of gasoline storage and distribution emissions: bulk storage and transfer losses (also referred to in this analysis as the "remainder" category), and service station underground tank loading losses (generally referred to as the "Stage I" category). Evaporative emission rates for these two sources are commonly expressed in terms of pounds of hydrocarbon vapor emitted to the atmosphere per thousand gallons of gasoline stored or transferred (lb/1000 gal).

Vehicle refueling emissions, or "Stage II" emissions, were treated as a third component of gasoline storage and distribution losses in EPA's original volatility study.[3] In this analysis, Stage II emissions have been removed from the stationary source portion of the emissions inventories and are treated (along with exhaust and evaporative emissions) as a mobile source. Emission factors for refueling emissions, expressed in terms of grams per mile (g/mi), are now incorporated into EPA's emission factor modeling. The effects of RVP control on these emissions were discussed earlier in this chapter, and the resulting emission factors are presented in Chapter 3.

1. Bulk Storage and Transfer ("Remainder") Losses

This category consists mainly of breathing and working (loading and unloading) losses resulting from the storage of gasoline in bulk terminals and the transferring of gasoline to the ships, tankers, and barges used for transport. The emission rates associated with bulk storage are dependent on several factors, including tank configuration (i.e., fixed or floating roof), tank dimensions, ambient and liquid storage temperatures, and vapor molecular weight and true vapor pressure (both of which are dependent on the RVP of the gasoline). Emissions generated during the loading of carriers are dependent on the method of filling (submerged or splash), bulk temperature of the fuel, and the vapor molecular weight and true vapor pressure. Equations for determining specific evaporative losses (i.e., breathing, loading) as a function of these and additional parameters have been developed for various types of storage and transport media, and are published in EPA's most recent version of the AP-42 document.[75]

The impact of controlling in-use fuel volatility on rates of evaporative emissions from the bulk storage and transfer of gasoline was estimated through the use of the relevant AP-42 equations. Holding the non-fuel related parameters of these equations constant, emission factors were calculated assuming RVP levels of 9.0, 10.0, and 11.5 psi. These emission factors were then used to determine dimensionless adjustment factors, which in turn were used to adjust the projected emission inventories for this category, as described below.

First, the ratios of the emission factors calculated for this category at 9.0 and 10.0 psi RVP to the emission factor at 11.5 psi RVP were determined. These dimensionless adjustment factors indicated that reducing in-use RVP from 11.5 to 9.0 psi would result in about a 17 percent decrease in emissions (i.e., the ratio of the emission factor at 9.0 psi to the emission factor at 11.5 psi is about 0.83). A curve was then fit to the three points and used to determine adjustment factors at other RVP levels, as described below.

As discussed in Section I of Chapter 3, EPA used data from the response to comments on the gasoline marketing study to establish the base year emission inventories for the bulk storage and transfer and Stage I categories.[76] The RVP of in-use fuel in the 1984 base year was assumed to be 11.5 psi in that document, while the 1983 average in-use RVP (see Section I of Chapter 3) was determined to be 11.0 psi. Thus, the base year inventory was adjusted for 11.0 psi RVP fuel, using the adjustment factor for 11.0 psi from the curve described above. The curve then was normalized to 11.0 (rather than 11.5) psi. From this point, the adjustment factors taken from this curve were used to adjust the projected inventories for the "remainder" category under various RVP control levels. The specific values of the adjustment factor corresponding to each RVP control level evaluated are presented in reference[77].

2. Service Station (Stage I) Losses

This category includes the breathing and loading losses associated with underground storage facilities at service stations. Losses in this category are commonly referred to as "Stage I" emissions, designating those emissions generated during the transfer of fuel between the tank truck and the service station. Emission rates from these sources are based primarily on the same parameters as the breathing and loading losses described in the preceding section.

The method used for developing RVP adjustments for Stage I emissions parallels that described above for the bulk storage and transfer category. Based on the ratio of the emission factor at 9.0 psi RVP to the emission factor at 11.5 psi RVP, a 2.5-psi in-use RVP reduction will result in about a 23 percent decrease in Stage I emissions. As in the case of the bulk storage and transfer category, reference [77] presents the Stage I inventory adjustment factors corresponding to each RVP control level examined.

III. Benzene Emissions from Gasoline-Fueled Vehicles as a Function of Fuel Parameters.

While the primary emphasis of this study is the effect gasoline volatility has on ambient ozone, the effect of benzene, a known carcinogen, is also important. In this section models are developed to estimate the benzene content of exhaust and evaporative hydrocarbon emissions for all pertinent model year (MY) gasoline-fueled vehicles based on the fuel parameters which can vary with RVP control. The benzene emission models are made as specific to vehicle type as possible based on catalyst type, fuel system, and the emissions standard under which the vehicle was produced. The benzene content of refueling emissions is only summarized here as it has already been addressed in detail in a separate study.[2]

The models developed below focus on the mass fraction of benzene to total hydrocarbon emissions. This minimizes the effect of large differences in the mass of benzene emissions when comparing data from vehicles of different control technologies and model years, and allows data to be used across technologies when specific data are limited or non-existent.

Fuel parameters chosen as relevant in the model for benzene exhaust emissions are the fuel benzene fraction, the fuel aromatics fraction, and to a lesser degree, the RVP. For evaporative emissions the fuel benzene fraction and the RVP of the fuel are the most relevant fuel parameters. For refueling, only the fuel benzene fraction is a relevant fuel parameter. An explanation of their selection is contained later in the discussion.

The following sections describe: 1) available data presented in the literature, 2) development of the exhaust and evaporative emission models from that data, 3) comparison of those models to the additional data to support its validity, 4) the effect of RVP control on fuel composition, and finally, 5) the effect this has on the benzene fraction of exhaust and evaporative emissions.

A. Literature Review

The information for this analysis was obtained from a variety of different studies. Ideally, each study would have provided information on the vehicle model year, catalyst type, fuel intake system, type of cycle over which emissions were taken, benzene and aromatic content and RVP of the fuel, and both benzene and total hydrocarbon emissions. In addition, each study would have run multiple tests varying independently the RVP, aromatic content, and benzene content of the fuel for each test vehicle. Unfortunately, these ideal conditions do not exist. Many studies did not include pieces of data which are required for this analysis. For example two studies [78,79] gave no fuel information whatsoever, and another study[80] gave no specification for the benzene content of the fuel, or benzene emissions (merely the benzene fraction of hydrocarbon emissions). When studies did provide the necessary information, they failed to perform independent testing of some or all of the relevant fuel parameters. Two studies [81,82] performed no independent testing of fuel parameters, and the remaining three [83,84,85] only performed independent testing of fuel fraction benzene. Table 2-58 compares qualitatively the applicability of the different studies reviewed.

Table 2-58

Description of Studies Used

REFERENCE NO.	VEHICLE INFORMATION			FUEL SPECIFICATIONS			EMISSION SPECIFICATIONS		INDEPENDENT VARIATION OF FUEL SPECS			ADDITIONAL DESCRIPTION
	NO. VEHICLES	CATALYST DESCRIPTION	FUELS PER VEHICLE/ TOTAL NO. FUELS	AROMATIC CONTENT	BENZENE CONTENT	RVP	BENZENE	TOTAL HYDROCARBON	BENZENE	AROMATICS	RVP	
83	5	Y	8/8	Y	Y	Y	Y	Y	Y			Complete data except aromatic content and RVP were highly correlated
84, 85	4	Y	2-3 /7	Y	Y	Y	Y	Y	Y			Different fuels used on different vehicles; Aromatic content and RVP highly correlated
81	4	Y	2/2	Y	Y	Y	Y	Y				No independent testing of fuel parameters
82	46	Y	1/2	Y	Y	Y	Y	Y				Only 1 fuel per vehicle; No independent testing of fuel parameters
80	15	Y	1/1	Y		Y		Y				Incomplete information; No independent testing of fuel parameters
78	5	Y	1/1				Y	Y				No fuel information
79	23	Y	1/1				Y	Y				No fuel information

Note: Additional studies listed in reference 86 were not included for reasons such as:

1) Incomplete information
2) Not properly maintained vehicles
3) Non-standard FTP cycle
4) Fuel other than gasoline used

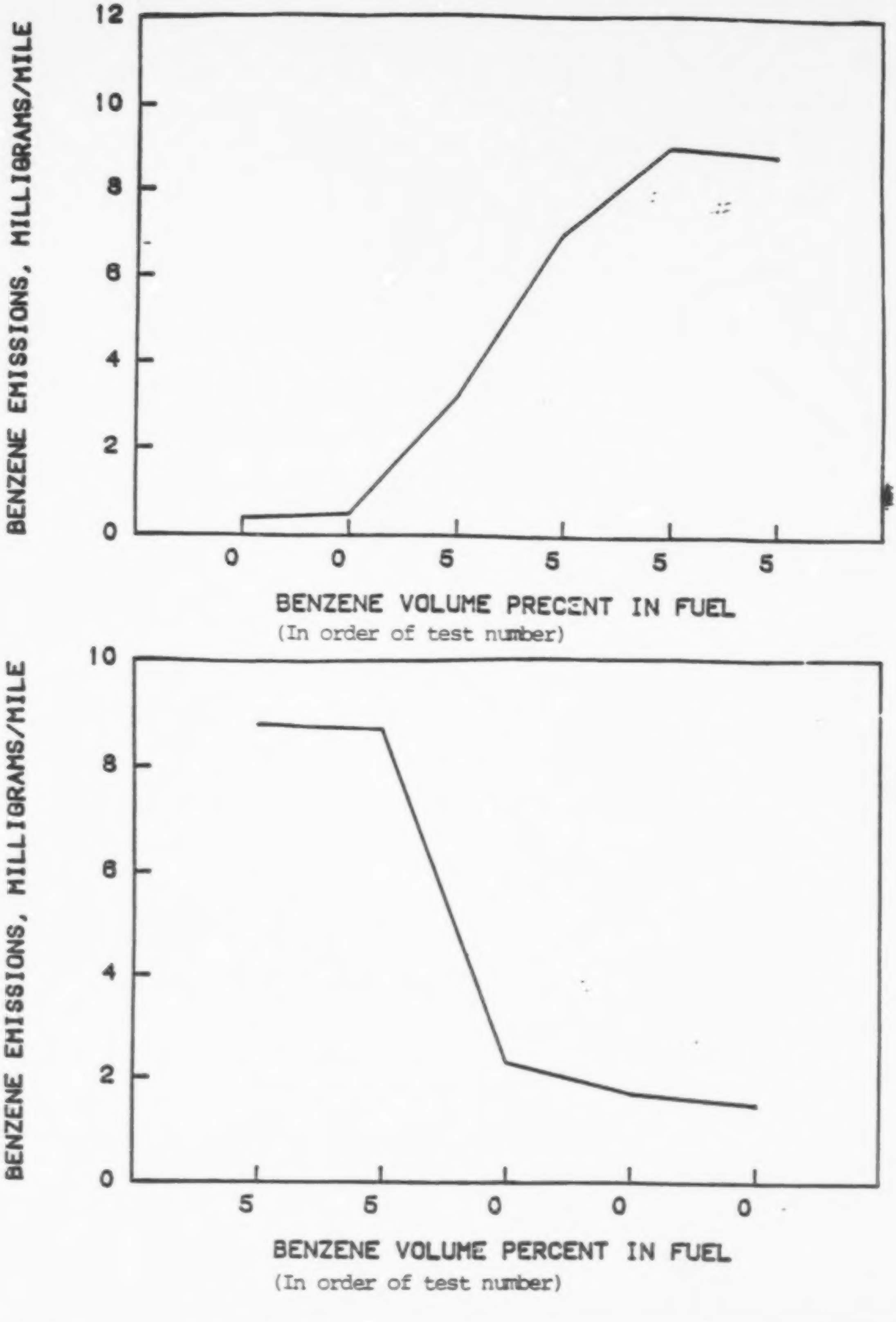
For exhaust emissions, the best available study was done for the Coordinated Research Council (CRC) by the National Institute for Petroleum and Energy Research (NIPER).[83] It met all of the above mentioned requirements except that it did not vary RVP and aromatic content independently. Thus, under the assumption that the aromatic content is the more significant of the two parameters for exhaust emissions, only benzene and aromatic content of the fuel were included in this analysis.

The data by Black and High although meeting the same requirements as the NIPER data, tested vehicles with different catalyst designs than NIPER.[84,85] Thus the two sets of data could not be combined for modeling purposes. In addition, Black and High tested no different vehicles with different fuels introducing a high degree of vehicle to vehicle variability into the data causing a separate modeling analysis on this data to be impractical. Thus the following model was developed using the NIPER data, and data from the other sources were used to evaluate its wider applicability.

For evaporative emissions, only two studies quantified benzene emissions. This provided a very small data base from which to work, and was further complicated by the study done by NIPER which showed a severe memory, or "carry-over" effect of benzene emissions from test to test when different fuels were used in successive tests.[83] For example, following a test conducted with a high benzene content fuel, a test with a low benzene content fuel will show higher than normal benzene emissions due to the canister still being loaded with large amounts of benzene from previous tests (see Figure 2-21). This "carry-over" effect suggests that the accuracy of any recorded data from other experiments may also be in error. However, after determining the existence of the carry-over problem, NIPER did a follow-up experiment involving four vehicles and two fuels for which they performed repetitive tests until the carry-over effect was eliminated. Unfortunately, one of the fuels contained no benzene (predictively producing no benzene emissions), and two of the vehicles had unrepresentatively low evaporative emissions compared to those described in Section II (i.e., extremely low diurnal emissions and low hot-soak emissions). This left only two tests on which benzene evaporative emissions could be modeled, one test of a carbureted vehicle, and the other test of a fuel-injected vehicle.

The data obtained by Black and High [84,85] could only be used as a check of the NIPER-based model for the carbureted vehicle, recognizing that the accuracy of the data is questionable due to the potential presence of carry-over. Black and High tested no fuel-injected vehicles. Therefore, the model for fuel-injected vehicles could not be verified.

Fig. 2-21- Benzene evaporative emissions as a function of fuel benzene level and number of test repetitions (4-vehicle average using MOBILE3 equation) [83]



B. Exhaust Emission Analysis

1. Selection of Relevant Fuel Parameters

Two fuel parameters are thought to have a significant effect on the benzene content of exhaust emissions; the benzene content, and the aromatic content of the fuel. The effect of the RVP will also be discussed below since that is the primary fuel parameter being addressed in this study.

The effect of benzene content is understandable since any benzene not combusted in the engine, nor subsequently oxidized by the catalyst, will be emitted as benzene. Therefore, the more benzene in the fuel, the greater the amount of benzene expected in the exhaust.

The effect of aromatic content is also understandable since the more complex aromatics in the fuel may combust incompletely leaving benzene as a product. Therefore, the higher the aromatic content of the fuel, the greater the amount of benzene expected in the exhaust. Other compounds could possibly recombine to produce benzene, but none have yet been specifically identified for use in a quantitative analysis.

The effect of RVP on benzene emissions is not as clear as the previous two fuel parameters. A decrease in RVP is essentially a measure of a decrease in the butane content of the fuel. This has been shown in Section III to result in decreased hydrocarbon emissions. As discussed in Chapter 4, this effect is due primarily to periodic enrichment of the fuel/air mixture when hydrocarbon vapors are purged from the canisters. This enrichment would not be expected to have any effect on the benzene fraction of hydrocarbon emissions only on the total amounts of both benzene and non-benzene emissions. Any other effects should be small relative to the effect of aromatics. Thus, without data to prove otherwise, the effect of RVP has to be ignored here, except for its effect on the benzene and aromatic content of gasoline.

2. Model Development and Analysis

As discussed earlier, the data from the NIPER study for 1984-85 MY vehicles, presented in Table 2-59, were used for the model development. A statistical analysis of the data presented with Figure 2-22 showed a significant difference between the benzene fraction of hydrocarbon emissions for vehicles with three-way (3w) catalysts and those with 3-way plus oxidation (3wox) catalysts. This is reasonable since the addition of the extra oxidation catalyst and the excess air could preferentially reduce various individual hydrocarbons. For this reason, the data was divided into two groups; vehicles with 3w catalysts, and vehicles with 3wox catalysts. Linear

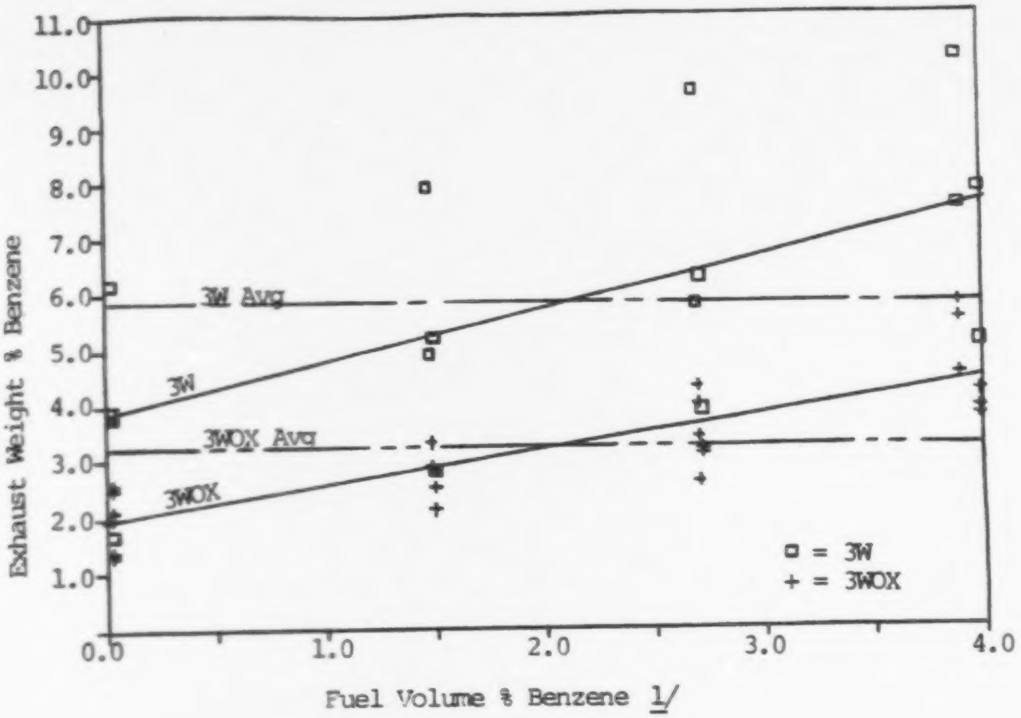
Table 2-59

NIPER Data Used for Exhaust Emission Modeling Analysis[83]

				BzEx				
			FArom	3w cat		3wox cat		
Fuel	RVP	FBz	(no Bz)	84 VW	85 Chevy	85 Chevy	85 Ford	85 Chrysler
1	10.8	0.03	25.7	3.9	1.7	1.4	1.3	2.0
2	10.6	1.50	25.6	5.2	2.8	2.8	2.1	2.5
3	10.6	2.72	25.2	6.3	3.9	3.1	3.2	2.6
4	10.4	3.99	24.9	7.8	5.1	4.2	3.9	3.8
5	10.1	0.03	40.1	6.2	3.8	2.1	2.5	2.6
6	9.8	1.48	39.4	7.9	4.9	2.9	3.3	3.3
7	9.8	2.70	38.9	9.6	5.8	4.0	3.4	4.3
8	9.8	3.90	38.2	10.2	7.5	5.5	5.8	4.5

Note: BzEx = Weight percent benzene in the exhaust
FBz = Fuel volume percent benzene
FArom = Fuel volume percent aromatics excluding benzene

Fig 2-22 Plot of 3way catalysts vs 3wox catalysts [83]



1/ For the above data

W%BzEx 3W cat	W%BzEx 3WOX cat
$\bar{x} = 5.79$	$\bar{x} = 3.21$
$S_x^2 = 5.61$	$S_x^2 = 1.31$

$$t_2 = \frac{(\bar{x} - \bar{y})}{\left[\frac{(n_x-1)S_x^2 + (n_y-1)S_y^2}{n_x + n_y - 1}\right]^{1/2} (1/n_x + 1/n_y)^{1/2}} = 4.61 \text{ (Signal)}$$

for $\nu = 16 + 24 - 2 = 38$
C.L. = 99%
$\alpha = (100\% - \text{C.L.})/2 = 0.005$
Therefore: $t_{\alpha,\nu} = 2.713$ (Noise)

Therefore we can be atleast 99% confident that there is a difference between the two types of catalysts. The t test done above is also a worst case situation, since by drawing the average through the data as seen above, you introduce additional variation due to the slope of the lines.

regressions were performed on each set of data with the following results:

$$BzEx(3w) = 1.0306(FBz)+0.17588(FArom)-1.9785 \quad (R^2=.996) \quad (1)$$
$$BzEx(3wox) = 0.6796(FBz)+0.06807(FArom)-0.3468 \quad (R^2=.965) \quad (2)$$

Where:
BzEx = weight percent benzene in the exhaust
FBz = volume percent benzene in the fuel
FArom = volume percent aromatics in the fuel excluding benzene

These equations were then applied to the test conditions in the other relevant studies[81,82] and the results compared to the actual data (see Table 2-B-1 in Appendix 2-B). As can be seen, these models give good correlation with the data for vehicles equipped with 3w and 3wox catalysts. However, neither equation seemed to accurately describe emissions for cars with only oxidation catalysts, or cars meeting pre-1980 emission standards. Instead, it was found that for these vehicles the average of the two equations gave the best correlation, as shown in Table 2-60 (and Table 2-B-1 in Appendix 2-B). Therefore, for pre-1980 cars, or cars after 1980 equipped only with oxidation catalysts, the equation

$$BzEx = .85511(FBz)+.12198(FArom)-1.1626 \quad (3)$$

was developed. A linear regression was not performed on the additional data to arrive at this or a similar equation for oxidation catalyst equipped vehicles because of the small number of fuels used in the other studies, and the lack of independence between fuel parameters.

C. Evaporative Emission Analysis

Data on the benzene content of evaporative emissions presented in Table 2-61, were limited to only one test each for carbureted and fuel-injected vehicles making any linear regression analysis impossible. Theoretical analysis was the only viable alternative remaining.

Two fuel parameters have a significant effect on the benzene content of evaporative emissions; the benzene content of the fuel, and RVP. With respect to the benzene content of the fuel, the vapor pressure of benzene is proportional to its level in the liquid fuel, so benzene emissions to the evaporative canister should be proportional to fuel benzene content. Any preferential treatment of benzene by the charcoal canister should be relatively consistent between fuel benzene levels in the range of consideration, so benzene emissions from the canister should also be proportional to fuel benzene content.

Table 2-60

Model Comparison for Ox-Cat and Pre-80 Cars

	Actual w% BzEx	Predicted 3W EQN	Predicted 3WOX EQN	Predicted Avg EQN
$\bar{x}$	3.61	4.64	2.72	3.68
S_x	1.516	1.497	.861	1.172
% error		28.5%	24.7%	1.9%

Table 2-61

NIPER Data Used for Evaporative Emission Modeling Analysis[83]

Vehicle	Cat	Fuel Syst	RVP	FV% Bz	V% Arom	W% Bz/HC
85 Ford	3wox	TBI	10.8	5.22	19.5	1.91
85 Plymouth	3wox	CARB	10.8	5.22	19.5	6.36

The effect of RVP, however, is more complicated. First, the fuel benzene content (and, thus, the vapor pressure of benzene) will tend to decrease with increased RVP (i.e., increased fuel butane content), but this is taken into account through the effect of fuel benzene content, as described above. In addition, increased RVP will increase the total amount of evaporative emissions. This increase will be primarily butanes. However, it will also include all other compounds to some degree, since the additional butane vapor generated from the temperature increase will increase the emission of all components in the vapor. This effect may differ for carbureted and fuel-injected vehicles since the ratio of hot-soak to diurnal emissions from a fuel-injected vehicle is much lower than from a carbureted vehicle, and RVP has a stronger effect on diurnal emissions than on hot-soak emissions.

No data are available to derive an empirical model. Derivation of theoretical relationships is hampered by the unknown effect of large increases in butane emissions on the canister's ability to adsorb benzene. Thus, two different models are proposed below. The first model is designed to represent a lower bound estimate of the effect of RVP on benzene emissions. The second represents an upper bound estimate.

The first model assumes that evaporative benzene emissions are directly proportional to the benzene content of the fuel, and inversely proportional to RVP:

$$EvBz = C(FBz)/RVP$$

Where: RVP = Reid vapor pressure
C = constant
Other notation as previously described.

When this model is applied to the data from the NIPER study,[83] which are shown in Table 2-61, the equations which result for both fuel-injected and carbureted vehicles are as follows.

$$EvBz = 3.952(FBz)/RVP \text{ (Fuel-Injected)} \quad (4)$$
$$EvBz = 13.159(FBz)/RVP \text{ (Carbureted)} \quad (5)$$

In an effort to substantiate equations 4 and 5, the additional data by Black and High were used (see Table 2-B-3 in Appendix 2-B).[84,85] Equation 5 was found to give reasonable correlation at RVP levels below 10 psi, but significantly overestimated the benzene emission fraction at higher RVP levels. No data were available for fuel-injected vehicles to evaluate equation 4.

Based on observation of trends in the Black and High data, a second model was developed which is more sensitive to RVP levels:

$$EvBz = A(FBz)(B-RVP)$$

Where: A and B are constants.

With this model, for the carbureted engine, an iterative procedure comparing values obtained from the model and the NIPER data with those obtained from the Black and High data gave a value of 0.5 for A and 13.23 for B. This correlates well with the Black and High data, but it must be remembered that the level of "carryover" effect in the Black and High data is unknown.

For fuel-injected vehicles, assuming B remains the same as in the carbureted case, A equals 0.151. The assumption that B is the same is based on the belief that the effect of RVP on evaporative emissions is the same (proportionally) for both fuel-injected and carbureted vehicles. As indicated above, this is probably not precisely the case. However, the lack of additional data for fuel-injected vehicles prevents derivation of a new value for B and the degree of error should hopefully be small. The equations based on the more RVP-sensitive model are then:

$$EvBz = 0.5(FBz)(13.23-RVP)^{*} \quad \text{(carbureted)} \qquad (6)$$
$$EvBz = 0.151(FBz)(13.23-RVP)^{*} \quad \text{(fuel-injected)} \qquad (7)$$

It is believed that these last equations may be more representative of actual emissions than equations 4 and 5 since the added sensitivity to RVP seems to allow the model to more closely predict trends observed in the Black and High data. However, due to the extremely small amount of data on which the models are based, the approach taken here is to use all four equations, two for carbureted vehicles, and two for fuel-injected vehicles to establish a range of projected emissions to allow for the high degree of uncertainty.

Since the only usable data were for recent model year vehicles, it is assumed that the benzene mass fraction of evaporative hydrocarbon emissions remains relatively constant for all vehicles. Therefore, any changes in benzene emissions by model year and standard under which the vehicles were produced will be compensated for by the change in quantity of hydrocarbon emissions for which there is more data available.

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* These equations are limited to RVP levels below 13.23 psi.

D. Refueling Emission Analysis

In a seperate study performed by EPA on the benzene fraction of refueling emissions, three parameters were found to have a significant effect: the fuel benzene content, the dispensed fuel temperature, and the temperature difference between the dispensed fuel and the in-tank fuel.[87] RVP was not found to be significant. This is understandable since refueling emissions are primarily displaced vapors from the fuel tank and the vapor pressure of benzene is solely a function of fuel benzene content and not RVP. The evaporation process which is enhanced by high RVP does not come into play.

The resulting equation derived from the analysis taking into account fuel spills during refueling is:

$$ReBz = 0.0451\ (FBz) - 1.60 \times 10^{-4}\ (T_D) - 4.24 \times 10^{-4}\ (\Delta T)$$

Where: ReBz = grams benzene emitted during refueling per gallon of fuel dispensed.
FBz = Volume percent benzene in the fuel
T_D = Temperature of the dispensed fuel
ΔT = Temperature difference between dispensed and in-tank fuel.

The nationwide average temperature of the dispensed fuel is 68.9°F while the average temperature difference between dispensed and in-tank fuel is 4.4°F. Therefore, the above equation is reduced to:

$$ReBz = 0.0451\ (FBz) - 0.01289 \qquad (8)$$

The fuel fraction benzene is the only true fuel parameter affecting the benzene refueling emissions. However, with RVP control, the benzene fuel fraction will change slightly. For this reason RVP control will affect the benzene fraction of refueling emissions.

E. Effect of RVP control on Fuel Composition

In-use control of RVP will be achieved primarily by reducing the quantity of butane in the gasoline pool (roughly two percent per 1.0 psi RVP reduction or up to seven percent for a 3.5 psi RVP reduction). If the quantity of butane in the fuel is reduced without any other compositional changes, the percentage of all other fuel constituents, including aromatics, would be expected to increase proportionately (i.e., by up to a factor 1.07). However, other compositional changes are expected which will either heighten or mitigate this general increase. No data are available concerning the effect of RVP control on benzene levels, in particular, but projections are available from the Bonner and Moore model of total fuel aromatic content for the baseline and control cases allowing investment and open NGL purchases (see Table 2-62). As can be seen, the nationwide average aromatic content increases, by 0.6 percent and 2.8 percent for RVP reductions of 1 psi and 2 psi, respectively, over the baseline level of 32.5 volume percent. Assuming benzene levels increase proportionately, then current benzene levels (roughly 1.34 percent based on the 1984 NIPER survey[88]) would increase by as little as 0.01 volume percent with a 1.0-1.5 psi RVP reduction from 11.5 RVP, to as high as 0.16 volume percent with a 3.5 psi RVP reduction to 8.0 (points below 9.5 psi are extrapolated from a plot of the data, and other points are interpolated).

F. Results

Using the equations and the estimates for fuel composition developed above for the current base case and future controlled RVP case, the resulting benzene emission fractions are shown in Table 2-63. The increases in benzene and aromatic content with maximum RVP control (i.e., 8 psi) cause a 15.2 percent increase in the benzene fraction of exhaust emissions. The benzene fraction of evaporative emissions, however, as they are also dependent on RVP, more than doubled. In the case of fuel-injected vehicles, however, this is still only a slight increase in absolute magnitude. Refueling emissions which are only affected by the change in fuel benzene content experienced only a 15 percent increase. These emission fractions will be used in Chapter 3 to estimate mobile source benzene emissions and related cancer incidences under the various regulatory scenarios.

Table 2-62

Changes in Aromatic Content (Vol %) Resulting from RVP Control[1]

With Investment, Open NGLs

	PADD				
	1	2	3	4 + 5 (ex. CA)[2]	Total U.S. (ex. CA)[3]
Baseline					
Unleaded Regular	38.8	32.0	31.3	31.7	32.2
Unleaded Premium	31.6	37.9	31.0	34.5	33.3
Leaded Regular	30.8	31.2	34.6	32.9	33.1
Weighted Average[4]	36.1	32.9	31.8	32.4	32.5
1 PSI RVP Reduction					
Unleaded Regular	37.9	33.1	31.2	32.2	32.4
Unleaded Premium	35.8	36.9	31.2	34.1	33.6
Leaded Regular	31.0	31.3	33.6	32.5	32.6
Weighted Average[4]	36.3	33.5	31.6	32.6	32.7
2 PSI RVP Reduction					
Unleaded Regular	38.3	33.6	32.4	33.0	33.3
Unleaded Premium	36.0	35.6	34.5	35.1	35.0
Leaded Regular	31.1	31.5	32.2	31.9	31.9
Weighted Average[4]	36.7	33.6	32.7	33.2	33.4

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[1] As predicted by Bonner and Moore RPMS model.

[2] Estimated as an average of PADDs 2 and 3.

[3] Total U.S. (ex. CA) estimated by volumetrically weighting of PADD aromatic content for PADDs 1,2,3,4 and 5 using PADD specific gasoline production.

[4] Average estimated by weighting the three gasoline grades by % of sales by volume.

Table 2-63

Benzene Fractions for Base and RVP Control Cases

RVP	Fuel V% Benzene	Fuel V% Aromatics	Model**	g Bz/g HC Exhaust	g Bz/g HC Evap	g/Bz/gal Fuel Refueling
11.5(Base)	1.34	32.5	A	.0512	.0116-.0153	.0475
			B	.0278	.0035-.0046	
			C	.0395		
11.0	1.34	32.5	A	.0512	.0149-.0160	.0475
			B	.0278	.0045-.0048	
			C	.0395		
10.5	1.35	32.6	A	.0515	.0169-.0184	.0480
			B	.0279	.0051-.0056	
			C	.0397		
10.0	1.35	32.8	A	.0518	.0178-.0218	.0480
			B	.0280	.0053-.0066	
			C	.0399		
9.5	1.37	33.2	A	.0527	.0190-.0256	.0489
			B	.0284	.0057-.0077	
			C	.0406		
9.0	1.39	33.6	A	.0536	.0203-.0294	.0498
			B	.0289	.0061-.0089	
			C	.0412		
8.5	1.43	34.6	A	.0558	.0221-.0338	.0516
			B	.0298	.0066-.0102	
			C	.0428		
8.0	1.50	36.3	A	.0595	.0247-.0392	.0548
			B	.0314	.0074-.0118	
			C	.0455		

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* Based on data from Table 2-62, these data are an extrapolation to 8.0 psi.

** For exhaust: Model A = vehicles with 3-way catalysts
Model B = vehicles with 3-way plus oxidation catalysts
Model C = vehicles Pre-1980 or Post-1980 vehicles with oxidation catalysts

For evap: Model A = carbureted vehicles
Model B = fuel-injected vehicles

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Appendix 2-A

Breakdown of Motor Vehicle Evaporative Emission Factors into Their Components

The evaporative emission factors used in this analysis were derived from the results of EPA's in-use emission factor (EF) test program. From July 1984 until March 1986, 321 vehicles were tested under this program. These vehicles were tested on: 1) commercial fuel with a nominal RVP of 11.7 psi, 2) a blended fuel with an RVP of 10.4 psi, and 3) Indolene fuel, with an RVP of roughly 9.0 psi, in that order. The complete test procedure was summarized in Table 2-10 under the heading of Post-July 1984.

The vehicles in the EF testing program have been separated by the condition of the vehicle, and by type of fuel metering system. Those vehicles having evaporative emission control malfunctions considered to be tampering were placed in the category of "tampered" vehicles. The remaining vehicles were categorized as "non-tampered" vehicles. As a subset of this group, those vehicles which exhibited no evaporative control system malfunctions were categorized as "problem-free" vehicles. Table 2-13 listed the potential malfunctions in the evaporative control systems, and also noted the malfunctions which were considered tampering. Within each of the above categories, the vehicles have also been separated into carbureted and fuel-injected vehicles.

Through consideration of the different evaporative emission rates for each of these categories, the individual components of evaporative emissions were determined. The components are: 1) the standard level, 2) the insufficient design capacity/purge effect, 3) the malmaintenance and defect effect, 4) the excess RVP effect, and 5) the tampering effect. The magnitude of each of the first four components was determined from the non-tampered and problem-free EF data base and is discussed in Section I below. The in-use EF sample is not thought to have a representative number of tampered vehicles, so the magnitude of the tampering effect has not been developed from this testing and is discussed separately in Section II. The emission components are used to determine the total evaporative emission factors for the various control scenarios in Chapter 3.

The third section will describe how the LDV emission rates were extrapolated to light-duty trucks and heavy-duty vehicles. The fourth section will describe how emissions are projected for vehicles produced in the future after the certification test procedure is amended.

I. LDV Evaporative Emission Components

The average measured emission rates for non-tampered and problem-free LDVs for each of the three fuels tested in the EF program are shown in Table 2-A-1. This analysis requires that the emission rates be known for in-use RVPs other than just these three levels. Therefore, curves were fit through the actual vehicle data for problem-free vehicle diurnal and hot-soak emissions for each type of fuel metering system. Diurnal emissions were curve-fit versus the uncontrolled diurnal index (UDI) as defined in Section II of Chapter 2, and hot-soak emissions were curve-fit versus RVP as defined in Section II of Chapter 2. For the problem-free fuel-injected diurnal emission equation, the best fit curve began rising at indices slightly lower than 1.0. To eliminate this anomaly, diurnal emissions on an 8.0 psi fuel were estimated to be 60 percent of the emissions on Indolene and re-curve-fit with the extra point. This percent was chosen so that the resulting best-fit curve was smooth and increasing. The best fit problem-free equations are listed in Table 2-A-1.

The non-tampered and problem-free emission rates have been separated into the four components listed previously. The remainder of this section will describe the process by which the magnitude of each component was determined.

A. Standard Levels

The standard levels represent the emission rates which would be seen if the vehicles emitted at the current 2-gram/test LDV standard on 9.0 psi RVP fuel. As it is necessary to separate the standard level into diurnal and hot-soak losses (which vary from vehicle to vehicle), it is assumed the ratio of hot-soak to diurnal emissions from problem-free vehicles is the same which would be seen if the standard level were met. Therefore, to determine the standard levels, the hot-soak and diurnal emissions on 9.0 psi RVP fuel from the problem-free sample are normalized such that their sum equals 2 grams/test. The emission rates observed from the problem-free vehicles and the calculated standard levels are presented in the first part of Table 2-A-2.

B. Insufficient Design Capacity/Purge Effect

The differences between the standard levels and the problem-free emission rates on 9.0 psi RVP fuel represent the insufficient design capacity/purge effect. This is based upon the assumption that a properly operating evaporative control system with no malfunctions should meet the 2-gram/test standard in-use. This effect is determined by subtracting the calculated standard levels from the emission rates for problem-free vehicles on 9.0 psi RVP fuel, and is shown at the bottom of Table 2-A-2. Note for fuel-injected vehicles, the

Table 2-A-1

Non-Tampered and Problem-Free 81+ LDV and LDT Evaporative Emission Rates (g/test)

Non-Tampered EF Test Data

Fuel Metering System	RVP(psi)	UDI*	Hot-Soak	Diurnal
CARB	9.0	1.0000	2.57	2.60
	10.4	1.4567	3.28	5.29
	11.7	2.0677	4.26	10.33
FI	9.0	1.0000	0.88	1.67
	10.4	1.4567	1.71	4.11
	11.7	2.0677	2.70	8.51

Problem-Free EF Test Data

Fuel Metering System	RVP(psi)	UDI*	Hot-Soak	Diurnal
CARB	9.0	1.0000	1.66	1.46
	10.4	1.4567	2.03	3.79
	11.7	2.0677	3.32	8.63
FI	9.0	1.0000	0.63	1.17
	10.4	1.4567	1.27	3.35
	11.7	2.0677	2.07	7.56

Best-Fit Problem-Free Equations:

$$\text{CARB Hot-Soak} = 0.17677\,(\text{RVP})^2 - 3.0735\,(\text{RVP}) + 14.9650$$

$$\text{CARB Diurnal} = 1.5498\,(\text{UDI})^2 + 1.6287\,(\text{UDI}) - 1.7274$$

$$\text{FI Hot-Soak} = 0.08553\,(\text{RVP})^2 - 1.2099\,(\text{RVP}) + 4.5867$$

$$\text{FI Diurnal} = 3.4304\,(\text{UDI})^2 - 4.1784\,(\text{UDI}) + 1.9335$$

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* Based on diurnal test conditions of 60-84°F heat build and a 40 percent full tank.

Table 2-A-2

Estimation of Standard Level and Insufficient Purge Effect for 81+ LDVs and LDTs (g/test)

Problem-Free Vehicle Average with 9.0 RVP	Hot Soak	Diurnal
CARB	1.66	1.46
FI	0.63	1.17
Standard Level*		
CARB	1.06	0.94
FI	0.70	1.30
Insufficient Design Capacity/ Purge Effect**		
CARB	0.60	0.52
FI	0.00	0.00

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* Problem-free average normalized to 2-gram standard.

** Problem-free average minus standard level; if negative, as for FI vehicles, considered zero.

insufficient design capacity/purge effect is non-existent because problem-free average emissions on 9.0 psi RVP fuel are under 2 grams/test. This is strong evidence that the majority of vehicles can meet the 2 gram/test standard in-use.

C. Malmaintenance and Defect Effect

Non-tampered vehicles, on the whole, show significantly higher average evaporative emission rates than do problem-free vehicles (a subset of non-tampered vehicles). This effect is assumed to be due to improper maintenance and equipment defects in the evaporative emission control system, but not to deliberate tampering. The distinction between malmaintenance/defects and tampering was made earlier in Chapter 2 in Table 2-13.

The malmaintenance and defect (M&D) effect is determined by subtracting the average problem-free emissions from the average non-tampered emissions for each fuel. The magnitude of the M&D effect was found to increase linearly with fuel RVP and UDI. This is expected since M&D problems result in partial or total disablement of the evaporative control system. The determination of this relationship for hot-soak emissions from fuel-injected vehicles is shown graphically in Figure 2-A-1. The top line shows the average emission rates on the three EF fuels for all non-tampered vehicles; the middle line shows these rates for only problem-free vehicles; and the bottom line shows the difference between the top two lines defined to be the M&D curve. A linear regression has been fitted to the curve to arrive at the M&D equation. This same method was used to develop the relationships for fuel-injected diurnal, carbureted diurnal, and carbureted hot-soak emissions.* The predicted M&D equations and emissions are summarized in Table 2-A-3.

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* Several carbureted vehicles had unexplainably high hot-soak emissions or hot-soak emissions which did not increase when tested on higher RVP fuels. These vehicles skewed the hot-soak M&D effect such that the M&D effect did not increase with increasing RVP. The carbureted hot-soak M&D effect was adjusted with the following conditions. The sum of the individual M&D effects on the three fuels was kept the same. The ratio of the slope of the carbureted hot-soak M&D line to the slope of the fuel-injected hot-soak M&D line was set equal to the ratio of the slope of the carbureted diurnal M&D line to the slope of the fuel-injected diurnal M&D line. The resulting equation and emissions are listed in Table 2-A-3.

Figure 2-A-1

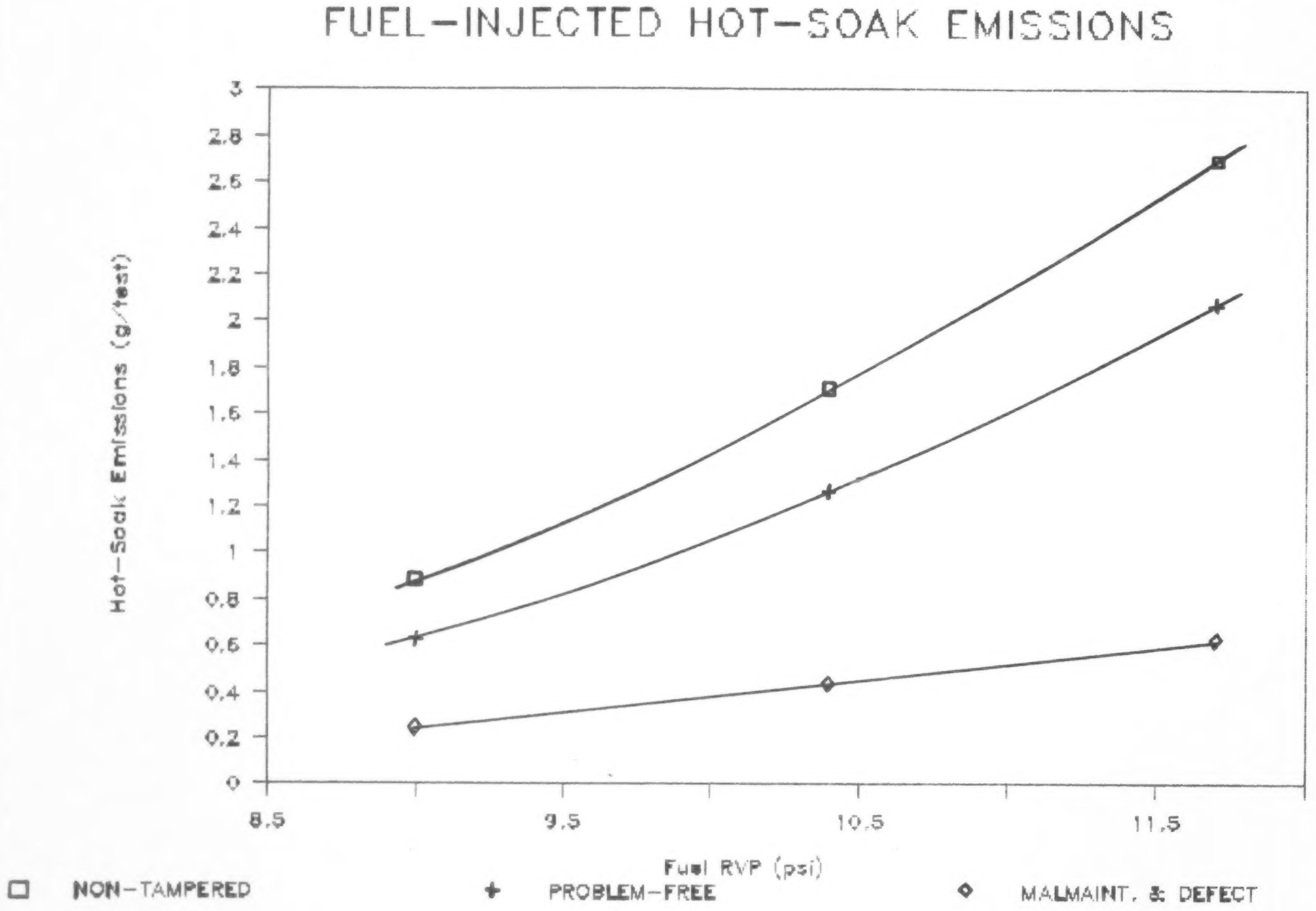
FUEL-INJECTED HOT-SOAK EMISSIONS
Hot-Soak Emissions (g/test)
3
2.8
2.6
2.4
2.2
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
8.5
9.5
10.5
11.5
Fuel RVP (psi)
□ NON-TAMPERED
+ PROBLEM-FREE
◇ MALMAINT. & DEFECT

Table 2-A-3

Malmaintenance and Defect Effect
for 81+ LDVs and LDTS (grams/test)

Fuel Metering System	RVP(psi)	UDI*	Hot-Soak	Diurnal
CARB	8.0	0.7547	0.62	1.06
	8.5	0.8705	0.71	1.12
	9.0	1.0000	0.80	1.19
	9.5	1.1454	0.88	1.26
	10.0	1.3094	0.97	1.34
	10.5	1.4961	1.06	1.44
	11.0	1.7104	1.14	1.55
	11.5	1.9581	1.23	1.68
FI	8.0	0.7547	0.11	0.42
	8.5	0.8705	0.18	0.47
	9.0	1.0000	0.25	0.53
	9.5	1.1454	0.32	0.59
	10.0	1.3094	0.39	0.65
	10.5	1.4961	0.46	0.73
	11.0	1.7104	0.53	0.82
	11.5	1.9581	0.60	0.92

M&D Equations:

CARB Hot-Soak = 0.17395 (RVP) - 0.76994

CARB Diurnal = 0.51370 (UDI) + 0.67194

FI Hot-Soak = 0.14068 (RVP) - 1.01835

FI Diurnal = 0.41542 (UDI) + 0.11016

---

* Based on diurnal test conditions of 60-84°F heat build and a 40 percent full tank.

D. Excess RVP Effect

The excess RVP effect represents the evaporative emissions which arise from operating vehicles on a fuel of a higher volatility than the fuel for which they were designed. Manufacturers apparently have designed current evaporative control systems to meet the 2-gram/test standard when operated on Indolene, with an average RVP of 9.0 psi without regard to the volatility of present commercial fuels. However, in-use gasoline in many areas of the country currently has an average volatility well above 9.0 psi. The magnitude of the in-use RVP effect will of course depend upon the actual volatility of the in-use fuel and in-use temperatures.

The excess RVP effect is defined as the difference between problem-free evaporative emissions on commercial fuel and problem-free evaporative emission on Indolene. The predicted excess RVP effect emissions and equations are listed in Table 2-A-4.

It be should noted, in cases where RVP is less than the vehicle's certification fuel RVP (for hot-soak emissions) and in cases when UDI is less than 1.0 (for diurnal emissions), the excess RVP effect is automatically set equal to zero. Also, due to the non-linearity of the diurnal excess RVP equation, the incremental excess RVP emissions for high UDIs become greater than the incremental emissions predicted by the tampered (uncontrolled) diurnal equations presented later in this appendix in Table 2-A-6. Therefore two sets of diurnal excess RVP equations are derived and presented in Table 2-A-4. The first set of diurnal excess RVP equations are derived as explained above. The second set of excess RVP diurnal equations makes the incremental increase in excess RVP emissions equal to the incremental increase in tampered diurnal emissions. The UDI where the switch of equations occurs is determined by setting the derivatives of the problem-free emissions equation and tampered diurnal emissions equation, with respect to UDI, equal to each other and solving for the resulting UDI. The UDI at which the switch occurs is also shown in Table 2-A-4.

E. Final Predicted Non-Tampered and Problem-Free Emissions

Table 2-A-5 contains the final predicted emissions for non-tampered and problem-free LDVs for the various test conditions. Non-tampered emissions are the sum of the standard level, insufficient design capacity/purge effect, the malmaintenance and defect effect, and the excess RVP effect. Problem-Free emissions are the sum of the standard level, insufficient design capacity/purge effect, and the excess RVP effect.

Table 2-A-4

Excess RVP Effect for 81+ LDVs and LDTs (g/test)

Fuel Metering System	RVP(psi)	UDI*	Hot-Soak	Diurnal
CARB	8.0	0.7547	0.00	0.00
	8.5	0.8705	0.00	0.00
	9.0	1.0000	0.00	0.00
	9.5	1.1454	0.10	0.72
	10.0	1.3094	0.29	1.61
	10.5	1.4961	0.56	2.73
	11.0	1.7104	0.92	4.14
	11.5	1.9581	1.38	5.95
FI	8.0	0.7547	0.00	0.00
	8.5	0.8705	0.00	0.00
	9.0	1.0000	0.00	0.00
	9.5	1.1454	0.19	0.46
	10.0	1.3094	0.42	1.16
	10.5	1.4961	0.69	2.18
	11.0	1.7104	1.00	3.64
	11.5	1.9581	1.36	5.72

Excess RVP Equations:

CARB Hot-Soak $= 0.17677\,(\mathrm{RVP})^2 - 3.0735\,(\mathrm{RVP}) + 13.34313$

CARB Diurnal (for $\mathrm{UDI} \leq 3.8386$)
$= 1.5498\,(\mathrm{UDI})^2 + 1.6287\,(\mathrm{UDI}) - 3.1785$

(for $\mathrm{UDI} > 3.8386$)
$= 13.52677\,(\mathrm{UDI}) - 26.02326$

FI Hot-Soak $= 0.08553\,(\mathrm{RVP})^2 - 1.2099\,(\mathrm{RVP}) + 3.96125$

FI Diurnal (for $\mathrm{UDI} \leq 2.5806$)
$= 3.4304\,(\mathrm{UDI})^2 - 4.1784\,(\mathrm{UDI}) + 0.7480$

(for $\mathrm{UDI} > 2.5806$)
$= 13.52677\,(\mathrm{UDI}) - 22.2123$

---

* Based on diurnal test conditions of 60-84°F heat build, and a 40 percent full tank.

Table 2-A-5

Predicted Non-Tampered Emissions for 81+ LDVs and LDTs
(g/test)

Fuel Metering System	RVP(psi)	UDI*	Hot-Soak	Diurnal
CARB	8.0	0.7547	2.28	2.52
	8.5	0.8705	2.37	2.58
	9.0	1.0000	2.46	2.65
	9.5	1.1454	2.64	3.44
	10.0	1.3094	2.92	4.41
	10.5	1.4961	3.28	5.63
	11.0	1.7104	3.72	7.15
	11.5	1.9581	4.27	9.09
FI	8.0	0.7547	0.81	1.72
	8.5	0.8705	0.88	1.77
	9.0	1.0000	0.95	1.83
	9.5	1.1454	1.21	2.35
	10.0	1.3094	1.51	3.11
	10.5	1.4961	1.85	4.21
	11.0	1.7104	2.23	5.76
	11.5	1.9581	2.66	7.94

Predicted Problem-Free Emissions for 81+ LDVs and LDTs
(g/test)

Fuel Metering System	RVP(psi)	UDI*	Hot-Soak	Diurnal
CARB	8.0	0.7547	1.66	1.46
	8.5	0.8705	1.66	1.46
	9.0	1.0000	1.66	1.46
	9.5	1.1454	1.76	2.18
	10.0	1.3094	1.95	3.07
	10.5	1.4961	2.22	4.19
	11.0	1.7104	2.58	5.60
	11.5	1.9581	3.04	7.41
FI	8.0	0.7547	0.70	1.30
	8.5	0.8705	0.70	1.30
	9.0	1.0000	0.70	1.30
	9.5	1.1454	0.89	1.76
	10.0	1.3094	1.12	2.46
	10.5	1.4961	1.39	3.48
	11.0	1.7104	1.70	4.94
	11.5	1.9581	2.06	7.02

---

* Based on diurnal test conditions of 60-84°F heat build, and a 40 percent full tank.

II. Tampering Effect

The emission rates for tampered vehicles have been derived from SHED testing on light-duty vehicles with removed canisters and/or fuel caps. The SHED tests were performed using 9.0 psi and 11.7 psi RVP fuels. The emissions at other RVPs and UDIs were determined through linear interpolation and are shown in the top portion of Table 2-A-6. Certain assumptions are made as part of this analysis. First, uncontrolled diurnal emissions are assumed to be the same regardless of either the type of disablement or the vehicle's fuel metering system. Secondly, for fuel-injected vehicles, uncontrolled hot-soak emissions are assumed to be the same for either canister removal or fuel cap removal due to the dominance of fuel tank emissions relative to those from the fuel injector. Finally, for carbureted vehicles, fuel cap removal is assumed not to lead to any increases in hot-soak emissions (i.e., the uncontrolled values are the same as the non-tampered hot-soak emissions shown in Table 2-A-5).

The difference between uncontrolled emissions and non-tampered vehicles is defined as the "tampering offset" to be used in the MOBILE3 program with tampering frequency estimates. The tampering offsets are given in the bottom half of Table 2-A-6.

III. Extrapolation of LDV Data to LDTs and HDGVs

The extrapolation of the light-duty vehicle evaporative emission rates to light-duty trucks and heavy-duty vehicles is done here exactly as it is done for MOBILE3.[89] Since little or no in-use test data exist for these vehicles, the emission rates are extrapolated based upon their relative standard levels. For LDTs, this means that evaporative emission rates will be exactly the same as for LDTs, as both of these vehicle classes must meet the same 2.0-gram/test standard under identical test procedures.

Beginning with the 1985 model year, HDGVs must meet either a 3.0-gram/test or 4.0-gram/test standard, depending upon their gross vehicle weight. Therefore, the evaporative emission rates for HDGVs under the 3.0- and 4.0-gram standards are those for LDVs multiplied by 1.5 and 2.0, respectively, and weighted by their respective sales fractions projected for 1987 -- 81.5 percent for 3-gram and 18.5 percent for 4-gram vehicles. This yields an overall heavy-duty/light-duty multiplicative factor of 1.5925. MOBILE3 assumes heavy-duty vehicles are completely carbureted, so the evaporative emission factors from only the carbureted vehicles are used. The resulting evaporative emission factors and the magnitude of each of the various components are shown in Table 2-A-7.

Table 2-A-6

Tampered Emissions of 81+ LDVs and LDTs

Uncontrolled Emission Rates (g/test)

Fuel Metering System	RVP (psi)	UDI*	Canister Removal		Gas Cap Removal	
			Hot-Soak	Diurnal	Hot-Soak	Diurnal
CARB	8.0	0.7547	7.52	12.27	2.28	12.27
	8.5	0.8705	8.94	13.75	2.37	13.75
	9.0	1.0000	10.36	15.40	2.46	15.40
	9.5	1.1454	11.79	17.25	2.64	17.25
	10.0	1.3094	13.21	19.34	2.92	19.34
	10.5	1.4961	14.63	21.72	3.28	21.72
	11.0	1.7104	16.05	24.45	3.72	24.45
	11.5	1.9581	17.47	27.61	4.27	27.61
FI	8.0	0.7547	3.64	12.27	3.64	12.27
	8.5	0.8705	4.42	13.75	4.42	13.75
	9.0	1.0000	5.20	15.40	5.20	15.40
	9.5	1.1454	5.98	17.25	5.98	17.25
	10.0	1.3094	6.75	19.34	6.75	19.34
	10.5	1.4961	7.54	21.72	7.54	21.72
	11.0	1.7104	8.21	24.45	8.21	24.45
	11.5	1.9581	9.00	27.61	9.00	27.61

Tampering Offsets (g/test)

Fuel Metering System	RVP (psi)	UDI*	Canister Removal		Gas Cap Removal	
			Hot-Soak	Diurnal	Hot-Soak	Diurnal
CARB	8.0	0.7547	5.24	9.75	0.00	9.75
	8.5	0.8705	6.57	11.17	0.00	11.17
	9.0	1.0000	7.90	12.75	0.00	12.75
	9.5	1.1454	9.15	13.81	0.00	13.81
	10.0	1.3094	10.29	14.93	0.00	14.93
	10.5	1.4961	11.35	16.09	0.00	16.09
	11.0	1.7104	12.33	17.30	0.00	17.30
	11.5	1.9581	13.20	18.52	0.00	18.52
FI	8.0	0.7547	2.83	10.55	2.83	10.55
	8.5	0.8705	3.54	11.98	3.54	11.98
	9.0	1.0000	4.25	13.57	4.25	13.57
	9.5	1.1454	4.77	14.90	4.77	14.90
	10.0	1.3094	5.24	16.23	5.24	16.23
	10.5	1.4961	5.69	17.51	5.69	17.51
	11.0	1.7104	5.98	18.69	5.98	18.69
	11.5	1.9581	6.34	19.67	6.34	19.67

Table 2-A-6 (Continued)

Uncontrolled Emission Equations:

All Diurnal = 12.74 (UDI) + 2.66

Hot-Soak
CARB Canister Removal = 2.84 (RVP) - 15.2

CARB Gas Cap Removal = same as Non-Tampered Emissions

FI Canister Removal or Gas Cap Removal = 1.56 (RVP) - 8.84

Tampering Offset Emissions Equations:

= Uncontrolled Emission - Non-Tampered Emissions

---

* Based on diurnal testing conditions of 60-84°F heat build, and a 40 percent full tank.

Table 2-A-7

Non-Tampered Evaporative Emission Rates for 85+ HDGVs
(g/test)

Component	RVP (psi)	UDI*	Hot-Soak	Diurnal
Standard Level	-	-	1.69	1.50
Insufficient Design Capacity/Purge	-	-	0.96	0.83
Malmaintenance/Defect**	8.0	0.7547	0.99	1.68
	8.5	0.8705	1.13	1.78
	9.0	1.0000	1.27	1.90
	9.5	1.1454	1.40	2.01
	10.0	1.3094	1.54	2.13
	10.5	1.4961	1.69	2.29
	11.0	1.7104	1.81	2.47
	11.5	1.9581	1.96	2.68
Excess RVP**	8.0	0.7547	0.00	0.00
	8.5	0.8705	0.00	0.00
	9.0	1.0000	0.00	0.00
	9.5	1.1454	0.16	1.15
	10.0	1.3094	0.46	2.56
	10.5	1.4961	0.89	4.35
	11.0	1.7104	1.47	6.59
	11.5	1.9581	2.20	9.48
Total Non-Tampered Average	8.0	0.7547	3.64	4.01
	8.5	0.8705	3.78	4.11
	9.0	1.0000	3.92	4.23
	9.5	1.1454	4.21	5.49
	10.0	1.3094	4.65	7.02
	10.5	1.4961	5.23	8.97
	11.0	1.7104	5.93	11.39
	11.5	1.9581	6.81	14.49

---

* Based on diurnal testing conditions of 60-84°F heat build, and a 40 percent full tank.

** Equations for the components are the same as LDVs multiplied by 1.5925.

LDV data on uncontrolled evaporative emissions were also used to develop the LDT and HDGV estimates, due to limited or lack of evaporative testing on these classes. The tampering offsets for LDTs are assumed to be equal to those developed from the LDV data, as indicated in Table 2-A-6. The methodology used to develop uncontrolled estimates for HDGVs is similar to that mentioned previously with respect to the non-tampered average.[89] Variations from the basic MOBILE3 method of extrapolating LDV evaporative data to HDGVs are detailed in the EPA technical report, "The Effect of Fuel Volatility on Controlled and Uncontrolled Evaporative Emissions," (EPA-AA-TEB-EF-86-01). Tampered emission estimates and tampering offsets for HDGVs are presented in Table 2-A-8.

IV. Projection of Evaporative Emissions for Future Vehicles with a Change in Certification Fuel RVP

The emission component equations listed in the previous sections are for all 1981+ gasoline vehicles. However, the inputs of RVP and UDI used in MOBILE3 are dependent on certification fuel RVP as explained in Section II of Chapter 2. A change in the certification conditions affects the components as explained below.

The breakdown of the 2.0 gram standard level into hot-soak and diurnal portions is assumed to be independent of the certification fuel RVP. The insufficient design capacity/purge effect is assumed to be eliminated in all vehicles after the certification test procedure is amended.

The malmaintenance and defect effect is assumed to be independent of the certification fuel RVP, only the RVP of the fuel in the tank. The majority of problems classified as malmaintenance and defects of the evaporative control system are problems which result in the disablement of the evaporative control system. Therefore, the emissions of these vehicles should not be dependent on the certification fuel RVP. The M&D equation inputs for RVP and UDI, as defined in Section II of Chapter 2, are calculated as if certification fuel RVP equals 9.0 psi.

The excess RVP effect is dependent on manufacturers' design goals, which presently appears to be based only on certification fuel RVP. Vehicle manufacturers will have to adjust the size of the evaporative canister and/or the amount of purge in order to meet the current 2.0 g standard on a different RVP certification fuel. The excess RVP equation input for RVP and UDI are calculated as defined in Section II of Chapter 2 as functions of the certification fuel RVP for which the vehicles are designed.

Table 2-A-8

Tampered Emissions of 85+ HDGVs*

Uncontrolled Emission Rates (g/test)

RVP (psi)	UDI	Canister Removal		Cap Removal	
		Hot-Soak	Diurnal	Hot-Soak	Diurnal
8.0	0.7547	11.21	22.55	3.64	22.55
8.5	0.8705	12.94	24.22	3.78	24.22
9.0	1.0000	14.67	26.08	3.92	26.08
9.5	1.1454	16.40	28.17	4.21	28.17
10.0	1.3094	18.12	30.53	4.65	30.53
10.5	1.4961	19.86	33.22	5.23	33.22
11.0	1.7104	21.58	36.30	5.93	36.30
11.5	1.9581	23.31	39.87	6.81	39.87

Tampering Offsets (g/test)

RVP (psi)	UDI	Canister Removal		Cap Removal	
		Hot-Soak	Diurnal	Hot-Soak	Diurnal
8.0	0.7547	7.57	18.54	0.00	18.54
8.5	0.8705	9.16	20.44	0.00	20.44
9.0	1.0000	10.75	21.85	0.00	21.85
9.5	1.1454	12.19	22.68	0.00	22.68
10.0	1.3094	13.47	23.51	0.00	23.51
10.5	1.4961	14.63	24.25	0.00	24.25
11.0	1.7104	15.65	24.91	0.00	24.91
11.5	1.9581	16.50	25.38	0.00	25.38

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* Included in EPA Technical Report, "The Effect of Fuel Volatility on Controlled and Uncontrolled Evaporative Emissions," by Celia Shih and Tom Darlington, (EPA-AA-TEB-EF-86-01).

Tampered emissions are assumed to be independent of certification fuel RVP, and dependent on the RVP of the fuel in the tank. Tampering results in the disablement of the evaporative control system and therefore the emissions from tampered vehicles do not depend on the certification fuel RVP. The tampered equation inputs for RVP and UDI are calculated as defined in Section II of Chapter 2 as if certification fuel RVP equals 9.0 psi. (The tampering offsets are affected by a change in certification fuel RVP because non-tampered emissions are affected by a change in certification fuel RVP.)

Table 2-A-9 contains the predicted non-tampered emissions for an LDV designed for a 2 gram/test standard on a certification fuel of 10.0 psi at various in-use RVPs. The choice of a certification fuel RVP of 10.0 psi here is arbitrary and intended only to show the emission effect of changing certification fuel RVP to a level different from 9.0 psi, as already presented in Table 2-A-5.

Table 2-A-9

Predicted Non-Tampered Evaporative Emission Rates for LDVs Designed for a Certification Fuel RVP of 10.0 psi

System	RVP(psi)	UDI*	Hot-Soak	Diurnal
CARB	8.0	0.5764	1.68	2.00
	8.5	0.6648	1.77	2.06
	9.0	0.7637	1.86	2.13
	9.5	0.8748	1.94	2.20
	10.0	1.0000	2.03	2.28
	10.5	1.1426	2.20	3.09
	11.0	1.3062	2.44	4.08
	11.5	1.4954	2.76	5.34
FI	8.0	0.5764	0.81	1.72
	8.5	0.6648	0.88	1.77
	9.0	0.7637	0.95	1.83
	9.5	0.8748	1.02	1.89
	10.0	1.0000	1.09	1.95
	10.5	1.1426	1.33	2.48
	11.0	1.3062	1.60	3.26
	11.5	1.4954	1.90	4.39

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* UDI used for excess RVP effect. Based on diurnal test conditions of 60-84°F heat build, 40% full tank, and certification fuel RVP equal to 10.0 psi. UDI used for M&D effect is same as UDI based on a certification fuel RVP of 9.0 psi.

APPENDIX 2-B

Detailed Benzene Emission Data

This appendix contains all of the data accumulated for evaluation of benzene emissions from light-duty gasoline vehicles. Not all of it proved useful in the analysis. Below is a description of what each table includes.

Table 2-B-1 - Contains all of the exhaust data used in the analysis to derive the emission models presented at the top of the table.

Table 2-B-2 - Contains additional exhaust data which was not useful in this analysis.

Table 2-B-3 - Contains the limited evaportive data available, various modeling equations proposed based on that data (not all are discussed in the write up due to poor correlation), back up data to test the models, and the constants for some of the models as a result of application of the back up data.

Table 2-B-1

Exhaust Data Used for Benzene Analysis

3-way Correlation: W%BzEx = 1.0306(FV%Bz)+.17588(FV%AROM)-1.9785
3WOX Correlation: W%BzEx = .67963(FV%Bz)+.06807(FV%AROM)-.34679
AVG: Pre-80 Correlation: W%BzEx = .85511(FV%Bz)+.12198(FV%AROM)-1.1626
POST 80 OX Cat: W%BzEx = .85511(FV%Bz)+.12198(FV%AROM)-1.1626

Pre 1975 Cars (No Cat)

Vehicle	FV%Bz	No Bz FV%AROM	W%BzEx	Predicted Pre-80
63 Chevy[84,85]	1.55	20.31	3.8	2.64
63 Chevy[84,85]	4.9	20.31	7.0	5.50
75-79 Cars No Cat				
79 Volare[82]	1.66	36.47	6.42	4.71
76 Celica[82]	1.66	36.47	4.55	4.71
75 Pinto[82]	1.49	25.61	2.50	3.24
76 Monarch[82]	1.49	25.61	1.75	3.24
77 Hornet[82]	1.49	25.61	3.23	3.24
77 F-10[82]	1.49	25.61	1.84	3.24
79 Rx-7[82]	1.49	25.61	2.67	3.24
OX CAT				
79 Chevette[82]	1.66	36.47	5.68	4.71
78 LTD[82]	1.66	36.47	3.26	4.71
78 Mustang[82]	1.66	36.47	6.68	4.71
76 Starfire[82]	1.49	25.61	3.71	3.24
76 Regency[82]	1.49	25.61	4.27	3.24
77 Skyhawk[82]	1.49	25.61	3.00	3.24
75 Valient[82]	1.49	25.61	3.16	3.24
78 Phoenix[82]		3.92	3.24	
79 Corolla[82]	1.49	25.61	2.93	3.24
77 Chevette[82]	1.49	25.61	2.36	3.24
78 Volare[82]	1.49	25.61	3.15	3.24
78 200SX[82]	1.49	25.61	2.08	3.24
79 Fairmont[82]	1.49	25.61	1.71	3.24
75 Cutlass[82]	1.49	25.61	2.39	3.24
78 Monarch[84,85]	.24	22.89	2.9	1.83
78 Monarch[84,85]	6.0	22.89	6.6	6.76
78 Monarch[84,85]	1.29	36.03	3.4	4.34
78 Monarch[84,85]	1.65	20.04	2.6	2.69
79 LTD[84,85]	1.29	36.03	5.1	4.34
79 LTD[84,85]	6.0	36.03	7.0	8.36
79 LTD[84,85]	1.65	20.04	2.8	2.69

Table 2-B-1 (continued)

3-way + OX Cat				
78 Ford[81]	2.16	42.2	3.1	3.99
			$\bar{x}=3.73$ $S_x=1.62$	$\bar{x}=3.88$ $S_x=1.34$

1980 Cars and later
No Cat

Vehicle	FV%Bz	No Bz FV%AROM	W%BzEx	Predicted Post-80
80 Cutlass[82]	1.49	25.61	3.24	3.24
OX Cat				
80 Scirocco[82]	1.49	25.61	3.53	3.24
80 Electra[82]	1.49	25.61	2.71	3.24
80 GLC[82]	1.49	25.61	2.04	3.24
81 Chevette[82]	1.49	25.61	3.53	3.24
81 Lynx[82]	1.49	25.61	1.72	3.24
82 LeBaron[82]	1.49	25.61	4.82	3.24
81 Concord[82]	1.49	25.61	3.27	3.24
80 LeBaron[82]	1.49	25.61	3.36	3.24
			$\bar{x}=3.13$ $S_x=.91$	$\bar{x}=3.24$ $S_x=0.0$
				Predicted 3W
3W Cat				
81 626[82]	1.49	25.61	1.96	4.06
81 Escort[82]	1.49	25.61	2.79	4.06
82 Citation[82]	1.49	25.61	7.74	4.06
81 Escort[82]	1.49	25.61	2.16	4.06
82 Mustang[82]	1.49	25.61	1.39	4.06
80 Lincoln[81]	2.16	42.2	6.0	7.67
80 Lincoln	2.36	27.4	4.2	5.29
80 Buick[81]	2.16	42.2	15.4	7.67
80 Buick	2.36	27.4	10.1	5.27
84 VW[83]	.03	25.7	3.9	2.57
84 VW	1.5	25.6	5.2	4.07
84 VW	2.72	25.2	6.3	5.26
84 VW	3.99	24.9	7.8	6.51
84 VW	.03	40.1	6.2	5.11
84 VW	1.48	39.4	7.9	6.48
84 VW	2.70	38.9	9.6	7.65
84 VW	3.90	38.2	10.2	8.76
85 Chevy[83]	.03	25.7	1.7	2.57
85 Chevy	1.5	25.6	2.8	4.07

Table 2-B-1 (continued)

Vehicle	FV%Bz	No Bz FV%AROM	W%BzEx	Predicted 3W
85 Chevy	2.72	25.2	3.9	5.26
85 Chevy	3.99	24.9	5.1	6.51
85 Chevy	.03	40.1	3.8	5.11
85 Chevy	1.48	39.4	4.9	6.48
85 Chevy	2.70	38.9	5.8	7.65
85 Chevy	3.90	38.2	7.5	8.76
			$\bar{x}$=5.77	$\bar{x}$=5.56
			S_x=3.27	S_x=1.68
3W + OX				Predicted 3W OX
81 Citation[82]	1.66	36.47	6.07	3.26
82 Rx-7[82]	1.49	25.61	1.25	2.41
82 Delta 88[82]	1.49	25.61	3.68	2.41
81 Jetta[82]	1.49	25.61	2.80	2.41
82 Chevette[82]	1.49	25.61	2.23	2.41
81 J-1000[82]	1.49	25.61	3.37	2.41
81 Citation[82]	1.49	25.61	3.46	2.41
81 Citation[82]	1.49	25.61	2.40	2.41
80 Caprice[81]	2.16	42.2	7.20	3.99
80 Caprice	2.36	27.4	4.5	3.12
85 Chevy[83]	.03	25.7	1.4	1.42
85 Chevy	1.5	25.6	2.8	2.42
85 Chevy	2.72	25.2	3.1	3.22
85 Chevy	3.99	24.9	4.2	4.06
85 Chevy	.03	40.1	2.1	2.40
85 Chevy	1.48	39.4	2.9	3.34
85 Chevy	2.70	38.9	4.0	4.14
85 Chevy	3.90	38.2	5.5	4.90
85 Ford[83]	.03	25.7	1.3	1.42
85 Ford	1.5	25.6	2.1	2.42
85 Ford	2.72	25.2	3.2	3.22
85 Ford	3.99	24.9	3.9	4.06
85 Ford	.03	40.1	2.5	2.40
85 Ford	1.48	39.4	3.3	3.34
85 Ford	2.70	38.9	3.4	4.14
85 Ford	3.90	38.2	5.8	4.90
85 Plymouth[83]	.03	25.7	2.0	1.42
85 Plymouth	1.5	25.6	2.5	2.42
85 Plymouth	2.72	25.2	2.6	3.22
85 Plymouth	3.99	24.9	3.8	4.06
85 Plymouth	.03	40.1	2.6	2.40
85 Plymouth	1.48	39.4	3.3	3.34
85 Plymouth	2.70	38.9	4.3	4.14
85 Plymouth	3.90	38.2	4.5	4.90
			$\bar{x}$=3.35	$\bar{x}$=3.09
			S_x=1.36	S_x= .98

Table 2-B-2

Additional Data Not Used for Benzene Analysis

Vehicle	CAT	FTP	RVP	V% Fuel Bz	V% Fuel AROM	g/mi HC Emis	g/mi Benz Emis	% Bz/HC
70 Delta[79]	None	X				2.29	.08	3.6
70 Dodge[79]	None	X				2.75	.09	3.2
70 Chevy[79]	None	X				3.30	.09	2.8
70 Ford[79]	None	X				3.78	.09	2.3
77 AMC[79]	None	X				1.17	.006	5.5
78 Chevy[79]	OX	X				.50	.03	5.3
78 Chevy[79]	OX	X				.31	.01	2.6
78 Ford[79]	OX	X				.43	.01	3.0
78 Ford[79]	OX	X				.51	.02	4.4
78 Ford[79]	3WOX	X				.11	.003	2.7
78 Pont[79]	3W	X				.26	.001	4.7
78 SAAB[79]	3W	X				.16	.01	7.6
79 Merc[79]	3WOX	X				.21	.01	3.6
78 Buick[79]	OX	X				1.71	.009	5.1
79 Merc[79]	3WOX	X				.69	.02	2.6
79 Merc[79]	3WOX	X				.68	.02	3.2
78 Ford[79]	OX	X				1.74	.06	3.5
78 Volvo[79]	3W	X				.61	.05	8.0
78 Olds[79]	OX	X				.87	.05	5.9
78 Chevy[79]	OX	X				.64	.03	5.3
78 Chevy[79]	OX	X				.45	.02	4.0
78 Ford[79]	OX	X				.64	.01	2.0
78 Chrys[79]	OX	X				4.57	.21	4.6
72 Chevy[80]	None	X	10.2		26.2	1.51	.057*	
74 Mazda[80]	None	X	10.2		26.2	1.47	.0718*	
75 Fury[80]	OX	X	10.2		26.2	.49	.0086*	
76 Ford[80]	OX	X	10.2		26.2	.55	.008*	
75 Chevy[80]	OX	X	10.2		26.2	.25	.0072*	
76 Cordoba[80]	None	X	10.2		26.2	.66	.0268*	
76 Fury[80]	None	X	10.2		26.2	1.45	.045*	
[80]	OX	X	10.2		26.2	.92	.0096*	
76 Ford[80]	OX	X	10.2		26.2	.63	.0122	
77 Chrys[80]	OX	X	10.2		26.2	.26	.0064*	
77 Fury[80]	OX	X	10.2		26.2	.84	.0236*	
77 Nova[80]	OX	X	10.2		26.2	.62	.0164	
77 Vega[80]	OX	X	10.2		26.2	.23	.0096*	
77 Rabbit[80]	OX	X	10.2		26.2	.18	.0047*	
77 Audi[80]	OX	X	10.2		26.2	.27	.0101*	
75 GM[78]	OX	X				.48	.0116	
75 GM[78]	OX	X				.70	.0154	
75 GM[78]	OX	X				.78	.0156	
75 GM[78]	OX	X				.73	.0208	
75 GM[78]	OX	X				.79	.0361	

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* Data represents benzene plus cyclohexane

Table 2-B-3

Evaporative Data Used for Benzene Analysis

CRC Data [83]

Vehicle	Fuel Syst	RVP	FV%Bz	W%Bz/HC
85 Ford	TBI	10.8	5.22	1.91
85 Plymouth	CARB	10.8	5.22	6.36

Modeling Equations

A) FIEW%Bz = 3.952(FV%Bz)/RVP
B) CEVW%Bz = 13.159(FV%Bz)/RVP
C) FIEW%Bz = 9.029(FV%Bz)$^{1/2}$/RVP
D) CEVW%Bz = 30.064(FV%Bz)$^{1/2}$/RVP
E) FIEW%Bz = .151(FV%Bz)(13.23-RVP)
F) CEVW%Bz = .5(FV%Bz)(13.23-RVP)
G) FIEW%Bz = .3(FV%Bz)$^{1/2}$(13.58-RVP)
H) CEVW%Bz = (FV%Bz)$^{1/2}$(13.58-RVP)

Black & High Data[84,85]

Vehicle	Fuel System	RVP	FV%Bz	Actual w%Bz/HC	Predicted Eqn B	Predicted Eqn B	Predicted Eqn F	Predicted Eqn H
63 Chevy	CARB	12.8	1.55	.6	1.59	2.92	.33	.97
63 Chevy	CARB	12.8	4.9	3.6	5.03	5.20	1.05	1.72
77 Mustang	CARB	9.8	1.29	1.8	1.73	3.48	2.21	4.29
77 Mustang	CARB	9.8	6.0	6.2	8.06	7.51	10.29	9.25
77 Mustang	CARB	12.3	1.65	1.6	1.76	3.14	.77	1.64
78 Monarch	CARB	8.4	.24	.5	.38	1.75	.58	2.54
78 Monarch	CARB	8.4	6.0	5.7	9.40	8.77	14.50	12.69
78 Monarch	CARB	9.8	1.29	1.8	1.73	3.48	2.21	4.29
78 Monarch	CARB	12.3	1.65	.6	1.76	3.14	.77	1.64
79 LTD II	CARB	9.8	1.29	2.2	1.77	3.48	2.21	4.29
79 LTD II	CARB	9.8	6.0	7.1	8.06	7.51	10.29	9.25
79 LTD II	CARB	12.3	1.65	.5	1.76	3.14	.77	1.64

Table 2-B-3 (continued)

Constants Based on Black & High Data

Vehicle	Const Eqn B	Const Eqn B	Const Eqn F	Cost Eqn H
63 Chevy	4.95	6.17	13.57	13.28
63 Chevy	9.40	20.82	14.27	14.42
77 Mustang	13.67	15.53	12.59	11.38
77 Mustang	10.13	24.81	11.87	12.33
77 Mustang	11.93	15.32	14.24	13.55
78 Monarch	17.5	8.57	12.57	9.42
78 Monarch	7.98	19.55	10.3	10.73
78 Monarch	13.67	15.53	12.59	11.38
78 Monarch	4.47	5.75	13.03	12.77
79 LTD II	16.71	18.98	13.21	11.74
79 LTD II	11.60	28.40	12.17	12.70
79 LTD II	3.73	4.79	12.91	12.69
	$\bar{x}$=10.48	$\bar{x}$=15.35	$\bar{x}$=12.78	$\bar{x}$=12.20
	S_x= 4.59	S_x= 7.71	S_x= 1.07	S_x= 1.35

Chapter 3

Environmental Impacts

This chapter examines the environmental impacts associated with each of the gasoline volatility control scenarios described in Chapter 1. The analyses presented in this chapter examine the impacts of long-term control of in-use and certification test fuel volatility to equal levels, and of additional short-term control of in-use fuel volatility.

Section I of this chapter discusses the computer models that were used (MOBILE3 and EKMA) and the input data. Section II presents the results of the nationwide emissions inventory analysis, and Section III describes the results of the city-specific ozone air quality analyses. The chapter concludes with an analysis of the reductions in toxic emissions (i.e., benzene) and cancer incidences that are projected to result from volatility control. An appendix to this chapter discusses butane reactivity.

I. Description of Models and Inputs

Two computer models were used in the development of the emissions inventories and ozone air quality analyses presented in this chapter, MOBILE3 and EKMA. MOBILE3 is EPA's model for calculating calendar-year, fleet-average motor vehicle emission factors for various gaseous pollutants. These factors are calculated for exhaust, evaporative, refueling, and total hydrocarbon (HC) emissions, and are expressed in grams per mile (g/mi). The differences between the released version of the MOBILE3 model and the in-house version of MOBILE3 used to perform the modeling for this analysis are discussed below.

These motor vehicle emission factors are then used as inputs in the projection of future HC emission inventories. These inventory projections, in turn, are used as inputs in the determination of cost-effectiveness and future ozone air quality. Future year projections are made assuming no control of volatility and assuming alternative control levels. Emission reductions, determined by comparing the "no-control" and "control" inventory projections for the same year, are used to calculate the estimated cost-effectiveness of a given control strategy. This process is detailed in Chapter 6. Changes in emission inventories over time, determined through comparing the projection year inventory (with or without control) to the base year inventory, are used as input data for the EKMA (Empirical Kinetic Modeling Approach). EKMA uses this and other information to predict future ambient ozone concentrations in specific urban areas. Inputs used to project future emission inventories are discussed in Section I.B., and inputs for the ozone air quality analysis are discussed in Section I.C. of this chapter.

A. MOBILE3: Calculation of Emission Factors

The released version of the MOBILE3 emission factor model and the standard assumptions used as input (e.g., temperatures) are well-documented, and are not repeated here.[1] This discussion focuses on the differences between the released version of the model and the "in-house" version input data used for this analysis.

The released version of MOBILE3 uses a number of standard input assumptions about factors that affect emissions, such as temperatures and fuel volatility. In a nationwide analysis like this one, these standard inputs are generally used whether one is modeling emission factors for the nation or for a specific urban area, thus ignoring the effects of various climates and regional differences in fuel volatility. However, since temperature plays such a dominant role with respect to evaporative emissions, city-specific data were gathered to develop city-specific emission factors for each of the 61 urban non-attainment areas examined. As is explained below, the nationwide emissions inventory projections are also based on this city-specific input data.

The two primary changes to the released version of MOBILE3 are the use of local temperatures and fuel RVP. The temperatures specified in EPA's vehicle test procedures, an ambient temperature range of 68° to 86°F (20° to 30°C), are used by the released version of MOBILE3 model in calculating temperature-dependent emissions.[2] These temperatures do not account for the wide variation in temperatures for different areas of the country. The fuel volatility of Indolene, EPA's test fuel for certification testing, is 9.0 pounds per square inch (psi) Reid Vapor Pressure (RVP). Although the released MOBILE3 uses an assumed fuel volatility of 11.5 psi as more representative of commercial fuels, this still is not representative of current in-use fuel volatility, which survey data show is even higher in some areas. As was seen in the preceding chapter, both temperatures and fuel volatility have a significant impact on the resulting emission factors. Considering the importance of temperatures and fuel volatility in determining vehicle hydrocarbon emissions, particularly evaporative emissions, EPA has used city-specific data for both temperature and volatility in the emission factors modeling for this analysis. The data used are described in detail in Sections I.A. 1. and 2. of this chapter.

Another significant difference between the released MOBILE3 model and the modeling done for this analysis pertains to the treatment of alcohol-blend fuels (i.e., gasohol, typically a blend of 90 percent gasoline and 10 percent ethyl alcohol). All other things equal, the addition of ethanol to gasoline results in a fuel with higher volatility (greater

RVP). The standard inputs for released MOBILE3 do not account for the use of alcohol-blend fuels and their emissions impacts. As is discussed in Chapter 7, EPA is considering several alternatives for volatility controls on alcohol-blend fuels. In order to account for the impact of these alternatives on hydrocarbon emissions, survey data on the market penetration of alcohol-blend fuels in the urban areas modeled are used. This is discussed in section I.A.3. of this chapter.

Finally, as noted above, the standard input data for released MOBILE3 is generally used to calculate emission factors that are then applied both nationally and to specific urban areas. Since the city-specific input data mentioned above result in more realistic emission estimates, the nationwide emission factors used in this analysis were estimated by a population-weighted average of the city-specific emission factors. This is described in section I.A.4.

The differences between the emission factors calculated using the standard inputs and the released version of MOBILE3 model and those calculated for this analysis are also discussed in the document "1983 NEDS Inventory Modifications," which is available in the docket.[3]

1. City-Specific Temperature Data

The released version of MOBILE3 assumes that the ambient temperature range that a vehicle is exposed to is 68° to 86°F (20° to 30°C), which are the temperatures specified for certification testing. Vehicle hydrocarbon emissions, especially evaporative emissions, are dependent on temperature. Both the maximum temperature and the diurnal temperature range have an impact on these emissions. While temperature correction factors are included with released MOBILE3, they generally have not been used in EPA's previous regulatory impact analyses.

As was seen in section I.A. of Chapter 2, ozone is mainly a summertime problem. Summertime temperatures over much of the nation, including many of the 61 non-California urban nonattainment areas, frequently exceed the 86°F maximum of the test procedure. In at least some of those areas, the diurnal temperature range of 24 F° (13 C°) used in EPA's evaporative emission test procedure is exceeded. EPA has accounted for this in its modeling of city-specific emission factors through the use of climatic data reflecting actual temperature observations in the areas modeled.

For different analyses, two sets of city-specific temperature data were used. Temperatures recorded on the design-value day were used in modeling environmental impacts, and July average temperatures were used in estimating some of the fuel credits gained as part of the economic analyses. The details of how these temperature data were incorporated into the calculation of emission factors were discussed in Chapter 2.

The use of these design-value date temperatures in the modeling of environmental impacts is based on the fact that the primary purpose of in-use fuel volatility control is to address widespread noncompliance with the ozone NAAQS. The goal is to estimate the number of current nonattainment areas that might achieve compliance with the ozone NAAQS under the various control scenarios. The design value day is the day EPA has used as the basis for modeling emission factors; thus, the analysis looks at whether the projected ambient ozone concentration for a specific urban area on a day like that on which the design value was recorded will drop below 0.125 ppm, meeting the NAAQS. If it does, the projection indicates that the control scenario under which this occurs will bring that area into attainment. Inventory projections are also based on these temperatures, with the tonnage reduction projections used in comparing and ranking various control programs.

The use of design-value date temperatures is inappropriate for the economic analysis, because the economic benefits of recovering evaporative emissions occur throughout the summer, and not only on high-ozone days. Instead, average July temperatures were used, both because they are more representative of average summertime conditions, and because they correspond to the in-use fuel volatility survey data that were available for use in this study. Summer fuel RVP survey data are unavailable for summer months other than July, so a 5-month weighting of temperature and RVP data could not be performed. Thus, the assumption was made that the generally higher RVP of summer fuel outside of July would be offset by generally lower temperatures.

Emission inventories and emission reductions obtainable in the projection years under the various control scenarios, calculated using July-average temperatures, are used in the process of estimating various recovery credits. This is discussed in section IV of Chapter 5. These temperatures may also be more appropriate for examining additional benefits of ozone reductions, such as welfare effects or crop damage.

Table 3-1 lists the 61 urban non-California nonattainment areas that were modeled, along with the date on which the ozone design value was recorded and the temperatures recorded on those dates. The dates on which the ozone design values were recorded were supplied by EPA's Office of Air Quality Planning and Standards (OAQPS).[4] Temperature data were obtained from appropriate issues of the National Oceanic and Atmospheric Administration's (NOAA) publications of "Monthly Climatological Data."

Table 3-1

Ozone Non-Attainment Area Design Value Dates and Temperatures

MSA/CMSA Name	Design Value Date	(°F) Tmin	(°F) Tmax
Boston Metro Area	July 17, 1982	73	97
Greater Connecticut Metro Area	July 30, 1983	72	90
New Bedford MA	June 9, 1984	67	88
Portland ME	June 6, 1983	51	74
Portsmouth-Dover-Rochester NH-ME	April 29, 1983	44	80
Providence RI	June 9,1984	73	95
Springfield MA	April 28, 1983	49	86
Worcester MA	June 14, 1983	60	87
Atlantic City NJ	July 21, 1983	70	96
New York Metro Area	June 8, 1984	72	92
Vineland-Millville-Bridgeton NJ	August 9, 1983	69	93
Allentown-Bethlehem PA-NJ	July 30, 1983	70	94
Baltimore MD	August 8, 1983	72	96
Erie PA	June 11, 1983	56	84
Harrisburg-Lebanon-Carlisle PA	June 13, 1983	64	88
Lancaster PA	September 6, 1982	49	80
Philadelphia Metro Area	August 17, 1983	62	87
Pittsburgh PA	August 3, 1983	64	87
Reading PA	August 17, 1983	60	88
Richmond-Petersburg VA	April 27, 1984	54	86
Scranton-Wilkes Barre PA	April 28, 1983	49	83
Washington DC-MD-VA	June 24, 1983	62	85
York PA	June 23, 1983	53	88
Atlanta GA	July 14, 1983	74	96
Birmingham AL	June 25, 1982	60	92
Charlotte-Gastonia-Rockhill NC-SC	August 23, 1983	73	103
Chattanooga TN-GA	August 22, 1983	73	100
Huntington-Ashland WV-KY-OH	July 15, 1983	61	96
Louisville KY-IN	July 12, 1983	70	93
Memphis TN-AR-MS	September 5, 1982	59	88
Miami-Hialeah FL*	August 2, 1982	81	96
Nashville TN	June 12, 1984	68	95
Tampa-St. Petersburg-Clearwater FL	June 4, 1984	67	88

Table 3-1
(continued)

Ozone Non-Attainment Area Design Value Dates and Temperatures

MSA/CMSA Name	Design Value Date	(°F)	
		Tmin	Tmax
Akron OH	August 15, 1983	62	85
Canton OH	August 24, 1983	59	92
Chicago Metro Area	July 15, 1983	77	95
Cincinnati Metro Area	June 25, 1982	50	81
Cleveland OH	August 19, 1983	66	91
Dayton-Springfield OH	August 21, 1983	72	100
Detroit MI	August 16, 1983	66	87
Grand Rapids MI	July 23, 1984	72	91
Indianapolis IN	July 25, 1982	65	88
Milwaukee Metro Area	August 28, 1984	69	94
Muskegon MI	June 26, 1983	66	90
Baton Rouge LA	September 19, 1982	73	91
Beaumont-Port Arthur TX	August 6, 1982	74	96
Brazoria TX	July 13, 1982	71	95
Dallas-Ft. Worth TX	August 27, 1983	76	96
El Paso TX	June 21, 1984	67	94
Galveston-Texas City TX**	July 21, 1982	81	91
Houston TX	August 30, 1983	76	93
Lake Charles LA	July 3, 1982	74	91
Long View-Marshall TX	August 1, 1983	69	96
New Orleans LA	June 7, 1982	68	93
San Antonio TX	September 3, 198	69	95
Tulsa OK	August 27, 1983	80	103
Kansas City MO-KS	August 15, 1984	77	96
St. Louis MO-IL	July 22, 1984	73	95
Denver-Boulder CO***	July 22, 1982	61	99
Salt Lake City-Ogden UT***	July 31, 1982	63	97
Phoenix AZ	August 3, 1984	85	107

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* Actual design value is December 24, 1982. Instead of this date, the highest ozone date at the same monitoring site during the summer control period was used.

** Actual design value is October 16, 1982. Instead of this date, the highest ozone date at the same monitoring site during the summer control period was used.

*** High-Altitude Area.

Examination of Table 3-1 reveals that the maximum temperature on the ozone design value date is greater than 86°F (30°C) for 52 of the 61 areas. The mean of the test procedure and standard MOBILE3 input temperatures for calculating exhaust emission factors, 77°F (25°C), is exceeded by the mean temperature on the design-value date in 40 of the 61 areas. The standard input diurnal temperature range for calculating evaporative emission factors, 24 F° (13 C°), is exceeded by the design-value date diurnal temperature range in 54 of the 61 areas. The uncontrolled diurnal index, discussed in section II.A.1. of Chapter 2, indicates that these temperatures result in in-use evaporative hydrocarbon emissions exceeding those under the standard temperature conditions.

The July average temperatures for the 61 urban areas modeled are shown in Table 3-2. These temperatures represent the "average" July day for each area, based on the mean of 30 years' observations (1941-1970 inclusive).[5] For those cities that did not have July average temperature data available, estimates were made by using the data for nearby cities, taking into account factors such as proximity to large bodies of water (e.g., Milwaukee data rather than Grand Rapids, MI data were used for Muskegon, MI). The cities used to estimate the temperature data for other cities are summarized in Table 3-3.

Relative to the design-value date temperatures, the July average temperatures are characterized by smaller diurnal ranges and slightly lower maximum temperatures. However, both the ranges and the maxima still tend to be greater than those of the EPA test procedure and standard MOBILE3 model. As will be shown in section II, the use of July average temperatures result in total inventories that are up to 3 percent smaller than those based on design value day temperatures. The emission reductions associated with each level of RVP control are also less when based on July average temperatures, relative to design value temperatures. The difference in the incremental (per 0.5 psi RVP) reductions associated with each set of temperatures is also smaller; however, this difference decreases at each step (0.5 psi) of control. At the lowest RVP levels evaluated, the differences in reductions are very small.

Another approach that was considered for the temperature input data was to use the averages of the temperatures of all days recording exceedances of the ozone NAAQS for each city. Due to the relatively small changes in the projections of emissions inventories and reductions between the two sets of temperature data described above, and the fact that such data were not available in time for these analyses, only the design value day and July-average temperatures were used in in this analysis. However, the use of temperature data from all NAAQS exceedance days will be considered in future analyses.

Table 3-2

July Average Temperatures for 61 Ozone Nonattainment Areas

MSA/CMSA Name	(°F) Tmax	(°F) Tmin
Boston MA (A)	81	65
Greater Conn (E)	81	61
New Bedford MA (E)	81	63
Portland ME (A)	79	57
Portsmouth-Dover-Rochester NH-ME (E)	83	57
Providence RI (A)	81	63
Springfield MA (E)	84	61
Worcester MA (E)	81	65
Atlantic City NJ (A)	85	65
New York NY (A)	85	68
Vineland-Millville-Bridgeton NJ (E)	85	65
Allentown-Bethlehem PA-NJ (E)	87	67
Baltimore MD (A)	87	67
Erie PA (E)	82	61
Harrisburg-Lebanon-Carlisle PA (E)	87	67
Lancaster PA (E)	87	67
Philadelphia PA-NJ (A)	87	67
Pittsburgh PA (A)	83	61
Reading PA (E)	87	67
Richmond-Petersburg VA(A)	88	68
Scranton-Wilkes Barre PA (E)	87	67
Washington DC-MD-VA (A)	88	69
York PA (E)	87	67
Atlanta GA (A)	87	69
Birmingham AL (E)	87	69
Charlotte-Gastonia-Rockhill NC-SC (A)	88	69
Chattanooga TN-GA (E)	87	69
Huntington-Ashland WV-KY-OH (E)	86	64
Louisville KY-IN (A)	87	66
Memphis TN-AR-MS (A)	92	72
Miami-Hialeah FL (A)	89	76
Nashville TN (A)	90	69
Tampa-St. Petersburg-Clearwater FL (E)	89	76
Akron OH (E)	85	62
Canton OH (E)	85	62
Chicago IL (A)	83	61
Cincinnati OH-KY-IN (A)	87	65
Cleveland OH (A)	82	61
Dayton-Springfield OH (E)	87	65
Detroit MI (A)	83	63
Grand Rapids MI (E)	83	63
Indianapolis IN (A)	85	65
Milwaukee WI (A)	80	59
Muskegon MI (E)	80	59
Baton Rouge LA (E)	90	73
Beaumont-Port Arthur TX (E)	94	73
Brazoria TX (E)	94	73
Dallas-Fort Worth TX (A)	96	74
El Paso TX (A)	95	70
Galveston-Texas City TX (E)	94	73
Houston TX (A)	94	73
Lake Charles LA (E)	90	73
Long View-Marshall TX (E)	96	74
New Orleans LA (A)	90	73
San Antonio TX (E)	96	74
Tulsa OK (E)	93	70
Kansas City MO-KS (A)	88	67
St. Louis MO-IL (A)	88	69
Denver-Boulder CO (A,H)	87	59
Salt Lake City-Ogden UT(A,H)	93	61
Phoenix AZ (A)	105	78

(A) = Actual 30-year (1941-70) mean temperatures.

(E) = Estimated 30-year mean temperatures, from nearest appropriate city for which actual temperatures were available.

(H) = High-altitude areas.

Table 3-3

Area for which July average temperatures were estimated	City temperatures used
Greater Connecticut	Hartford CT
New Bedford MA	Providence RI
Portsmouth-Dover-Rochester NH-ME	Concord NH
Springfield MA	Hartford CT
Worcester MA	Boston MA
Vineland-Millville-Bridgeton NJ	Atlantic City NJ
Allentown-Bethlehem PA-NJ	Philadelphia PA
Erie PA	Cleveland OH
Harrisburg-Lebanon-Carlisle PA	Philadelphia PA
Lancaster PA	Philadelphia PA
Reading PA	Philadelphia PA
Scranton-Wilkes Barre PA	Philadelphia PA
York PA	Philadelphia PA
Birmingham AL	Atlanta GA
Chattanooga TN-GA	Atlanta GA
Huntington-Ashland WV-KY-OH	Charleston WV
Tampa-St. Petersburg-Clearwater FL	Miami FL
Akron OH	Columbus OH
Canton OH	Columbus OH
Dayton-Springfield OH	Cincinnati OH
Grand Rapids MI	Detroit MI
Muskegon MI	Milwaukee WI
Baton Rouge LA	New Orleans LA
Beaumont-Port Arthur TX	Houston TX
Brazoria TX	Houston TX
Galveston-Texas City TX	Houston TX
Lake Charles LA	New Orleans LA
Longview-Marshall TX	Dallas-Fort Worth TX
San Antonio TX	Dallas-Fort Worth TX
Tulsa OK	Oklahoma City OK

2. City-Specific Alcohol-Blend Market Shares

There are two reasons for using data on the market penetration of alcohol-blend fuels for each of the cities modeled. In general, alcohol-blend fuels using ethanol are of higher volatility than the gasoline from which they are made. Thus, accounting for the fraction of gasoline use that is represented by alcohol blends results in more accurate emission factors. In addition, EPA is considering several alternatives for the treatment of alcohol blends under any regulatory program for limiting gasoline volatility, including allowing such blends a 1.0 psi RVP allowance above the gasoline requirements. City-specific alcohol blend market fractions can then be used to estimate the emissions impacts of such alternatives, which are discussed in Chapter 7.

Alcohol blend market penetration data for July 1983 and September 1985 were used in the modeling of emission factors. The 1983 data were used in adjusting the base year (1983) inventories, while the 1985 data (the most recent available at the time of this analysis) were assumed to apply to all of the projection years. These values are presented in Table 3-4.

As noted above, alcohol blend fuels will have higher volatility than the base gasoline from which they are made. The assumption made here is that the RVP of gasohol is 1.2 psi greater than that of gasoline (in the absence of requirements that it be otherwise, as discussed below). This offset in volatility represents 1.0 psi due to splash blending of alcohol and gasoline, and 0.2 psi due to the effects of commingling (of straight gasoline and gasohol) in vehicle fuel tanks, as discussed in section II.B. of Chapter 2. This difference is assumed to apply to the 1983 base-year emission factors. (The impact of the higher RVP of alcohol-blend fuels on motor vehicle hydrocarbon emission factors was discussed in detail in Chapter 2.)

The latest alcohol-blend market fraction data available for use in this modeling were for September 1985. These data were assumed to apply to all of the projection years. Alcohol-blend fuel production and market penetration are sensitive to a number of factors, among them the availability of state tax exemptions, consumer acceptance, and crude oil prices. Market penetrations of alcohol-blend fuels can be expected to vary considerably in the future. However, most of the factors impacting the rate of gasohol use are very difficult to project, especially in the long term.

In using these data for the projection years, these assumptions were used: Where alcohol blends are required to meet the same RVP restrictions as gasoline, the in-use RVP of

Table 3-4

Base-Year (1983) and Most Recent (1985)
Ethanol Fuel Market Fraction Data
(Source: Alcohol Week[6] unless noted)

MSA/CMSA Name	July 1983	Sept 1985
Boston MA	0.0	0.0
Greater Connecticut	0.0	0.0
New Bedford MA	0.0	0.0
Portland ME	0.0	0.0
Portsmouth-Dover-Rochester NH-ME	0.0	0.0
Providence RI	0.0	0.0
Springfield MA	0.0	0.0
Worcester MA	0.0	0.0
Atlantic City NJ	0.0	0.0
New York NY	0.0	0.0
Vineland-Millville-Bridgeton NJ	0.0	0.0
Allentown-Bethlehem PA-NJ	0.0	0.0
Baltimore MD	0.0	0.0
Erie PA	0.0	0.0
Harrisburg-Lebanon-Carlisle PA	0.0	0.0
Lancaster PA	0.0	0.0
Philadelphia PA-NJ	0.0	0.0
Pittsburgh PA	0.0	0.0
Reading PA	0.0	0.0
Richmond-Petersburg VA	2.3	19.7
Scranton-Wilkes Barre PA	0.0	0.0
Washington DC-MD-VA	0.0	0.0
York PA	0.0	0.0
Atlanta GA	0.0	0.0
Birmingham AL	0.0	11.9
Charlotte-Gastonia-Rockhill NC-SC	2.4	0.6*
Chattanooga TN-GA	0.0	12.7
Huntington-Ashland WV-KY-OH	0.0	0.0
Louisville KY-IN	0.0	37.9*
Memphis TN-AR-MS	0.0	12.7
Miami-Hialeah FL	8.3	8.9
Nashville TN	0.0	12.7
Tampa-St.Petersburg-Clearwater FL	8.3	8.9

Table 3-4
(continued)

Base-Year (1983) and Most Recent (1985) Ethanol Fuel Market Fraction Data

(Source: Alcohol Week[6] unless noted)

MSA/CMSA Name	July 1983	Sept 1985
Akron OH	10.6	1.8
Canton	10.6	1.8
Chicago IL	4.4	29.9
Cincinnati OH-KY-IN	10.6	1.8
Cleveland OH	10.6	1.8
Dayton-Springfield OH	10.6	1.8
Detroit MI	21.7	13.0
Grand Rapids MI	21.7	13.0
Indianapolis IN	0.0	32.7
Milwaukee WI	0.0	0.7*
Muskegon MI	21.7	13.0
Baton Rouge LA	0.0	10.7*
Beaumont-Port Arthur TX	0.0	4.1
Brazoria TX	0.0	4.1
Dallas-Ft. Worth TX	0.0	4.1
El Paso TX	0.0	4.1
Galveston-Texas City TX	0.0	4.1
Houston TX	0.0	4.1
Lake Charles LA	0.0	10.7*
Long View-Marshall TX	0.0	4.1
New Orleans LA	0.0	10.7
San Antonio TX	0.0	4.1
Tulsa OK	2.4	0.0
Kansas City MO-KS	0.0	23.5
St. Louis MO-IL	4.4	29.9
Denver-Boulder CO**	2.4	16.2
Salt Lake City-Ogden UT**	0.0	0.8*
Phoenix AZ	0.0	0.0
Nationwide	3.7	7.4*

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* Source: Alcohol Update.[7]

** High-altitude area.

blends is assumed to be 0.2 psi greater than that of gasoline, as a result of commingling. This was discussed in section II.B. of Chapter 2. Where the impact of providing alcohol-blends with a 1.0 psi RVP allowance was examined, the in-use blend RVP was assumed to be 1.2 psi greater than that of gasoline, reflecting both the 1.0 psi "allowance" and the 0.2 psi commingling effect.

Alcohol-blend fuel market penetrations and in-use commercial fuel volatility (discussed in the following section) have time-dependent trends. This situation differs from that of temperatures, which vary unpredictably and without directional trends over time. For both alcohol-blend market penetrations and in-use RVP, the 1985 data were the latest available for this analysis and are assumed to apply in all of the projection years. Preliminary 1986 data on these factors showed no significant differences from the 1985 data actually used (on an national average basis), lending additional support to the appplication of these data to the projection years.

The discussion above refers only to ethanol-blend fuels (gasohol). Consideration was given to taking similar steps with respect to commercially available (i.e., to retail consumers) methanol-gasoline blends. However, since no methanol blends are currently being sold at the retail level, no effort was expended to include methanol-gasoline blends in this environmental impact analysis.

3. City-Specific In-Use Fuel Volatility

The last of the city-specific input information used in the calculation of emission factors was data on current in-use fuel volatility (as of July 1985). This information was derived from two sources, the annual fuel surveys conducted by the Motor Vehicle Manufacturer's Association (MVMA), and the American Society for Testing and Materials' (ASTM) voluntary fuel volatility guidelines.[8,9]

The city-specific fuel RVP data used in the analysis are shown in Table 3-5. All of the 1983 values are average volatilities for non-alcohol-containing unleaded gasolines taken from the MVMA Gasoline Survey for Summer 1983.[8] For 1985, the Summer 1985 MVMA Gasoline Survey average volatility of non-alcohol-containing unleaded gasoline was used, except for those areas where the survey RVP was less than the corresponding ASTM limit, in which cases the ASTM limit was used. This was done under the assumption (supported by in-use volatility trends since the mid 1970s) that in-use volatility in those areas would continue to increase, at least until the ASTM limits were reached. As with average July temperatures,

Table 3-5

In-Use Fuel Volatility (RVP) Data

MSA/CMSA Name	In-Use RVP* (psi) 1983	In-Use RVP* (psi) 1985
Boston MA	10.7	11.5
Greater Connecticut	10.7	11.5
New Bedford MA	10.7	11.5
Portland ME	10.7	11.5
Portsmouth-Dover-Rochester NH-ME	12.7	13.5
Providence RI	10.7	11.5
Springfield MA	12.7	13.5
Worcester MA	10.7	11.5
Atlantic City NJ	10.6	11.5
New York NY	10.6	11.5
Vineland-Millville-Bridgeton NJ	10.6	11.5
Allentown-Bethlehem PA-NJ	10.6	11.5
Baltimore MD	11.0	11.5
Erie PA	11.5	12.1
Harrisburg-Lebanon-Carlisle PA	10.6	11.5
Lancaster PA	10.6	11.5
Philadelphia PA-NJ	10.6	11.5
Pittsburgh PA	11.5	12.1
Reading PA	10.6	11.5
Richmond-Petersburg VA	11.0	11.5
Scranton-Wilkes Barre PA	12.6	13.5
Washington DC-MD-VA	11.0	11.5
York PA	10.6	11.5
Atlanta GA	10.1	10.3
Birmingham AL	11.6	11.8
Charlotte-Gastonia-Rockhill NC-SC	10.1	10.3
Chattanooga TN-GA	10.1	10.3
Huntington-Ashland WV-KY-OH	11.0	11.5
Louisville KY-IN	11.0	11.5
Memphis TN-AR-MS	10.1	10.3
Miami-Hialeah FL	10.3	11.5
Nashville TN	11.6	11.8
Tampa-St.Petersburg-Clearwater FL	10.3	11.5

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* In-Use RVP associated with ozone design value day.

Table 3-5
(continued)

In-Use Fuel Volatility (RVP) Data

MSA/CMSA Name	In-Use RVP* (psi) 1983	In-Use RVP* (psi) 1985
Akron OH	11.5	12.1
Canton OH	11.5	12.1
Chicago IL	11.7	11.9
Cincinnati OH-KY-IN	11.5	12.1
Cleveland OH	11.5	12.1
Dayton-Springfield OH	11.5	12.1
Detroit MI	11.3	12.0
Grand Rapids MI	11.7	11.9
Indianapolis IN	11.7	11.9
Milwaukee WI	11.7	11.9
Muskegon MI	11.7	11.9
Baton Rouge LA	10.2	10.9
Beaumont-Port Arthur TX	9.9	10.7
Brazoria TX	9.9	10.7
Dallas-Ft.Worth TX	9.9	10.7
El Paso TX	8.8	9.5
Galveston-Texas City TX	10.2	10.5
Houston TX	10.2	10.5
Lake Charles LA	10.2	10.9
Long View-Marshall TX	9.9	10.7
New Orleans LA	11.7	12.4
San Antonio TX	10.2	10.5
Tulsa OK	9.7	10.3
Kansas City MO-KS	9.7	10.3
St. Louis MO-IL	10.4	10.4
Denver-Boulder CO**	10.0	10.2
Salt Lake City-Ogden UT**	9.6	10.0
Phoenix AZ	8.6	9.0

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* In-Use RVP associated with ozone design value day.
** High-altitude area.

RVP information was not available for all of the 61 urban areas. In those non-survey areas for which no in-use volatility data were available, the RVP of the nearest survey area, based on the gasoline distribution system network of pipelines and commonality of ASTM classification, was used for the volatility of the non-survey urban areas.

The RVPs listed in Table 3-5 are the RVPs for the month in which each areas' design value day occurred. The summer gasoline surveys are taken in July, whereas the design value days occur in different months for the 61 urban areas. For six areas*, the ASTM classification for the month in which the design value day occurred and the July ASTM classification are not the same. Therefore, an additive correction was made to the July survey RVP for these areas to adjust the RVP level to the correct ASTM class for the month in which the ozone design value day occurred. For example, the July 1985 survey RVP for Nashville is 10.3 psi, during an ASTM classification C/B month (Class B fuel was assumed, since 10.3 psi is much closer to the Class B limit than to the Class C limit). The design value day for Nashville occurred in June, an ASTM classification C month. So the RVP used for this analysis was adjusted up to 11.8 psi. The additive 1.5 psi upward adjustment is the difference between ASTM volatility specifications for Class B and Class C fuels of 10.0 psi and 11.5 psi, respectively. As with the city-specific alcohol-blend market penetration data discussed in the preceding section, the 1983 RVP data were used in adjusting the base-year inventories and the 1985 data were assumed to apply in all of the projection years.

4. Nationwide HC Emission Factors

As mentioned in the introduction to this chapter, previous EPA analyses of mobile source programs have generally assumed that the same input data, and thus emission factors, apply on both local (city-specific) and national scales. The preceding sections have presented city-specific information used in calculating hydrocarbon emission factors for each of the urban, non-California ozone nonattainment areas modeled for this analysis. This section discusses the incorporation of that information in the calculation of nationwide emission factors. The resulting fleetwide exhaust, evaporative, refueling, and total hydrocarbon emission factors are presented in a series of tables. Total hydrocarbon emission factors for each gasoline-fueled vehicle category (light-duty vehicles, light-duty trucks, and heavy-duty vehicles) are also presented.

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* Portsmouth-Dover-Rochester, NH-ME; Springfield, MA; Scranton-Wilkes Barre, PA; Birmingham, AL; Nashville, TN; and New Orleans, LA.

The nationwide emission factors presented below are based on a population-weighted average of the emission factors calculated for the 61 urban non-California ozone nonattainment areas modeled. The 1980 census populations of the 61 areas are shown in Table 3-6.

Tables 3-7 through 3-14 present the nationwide emission factors used in this analysis, based on the city-specific inputs and population weighting described above. The total HC emission factors (sum of exhaust, evaporative, and refueling HC emissions) are presented for light-duty gasoline-fueled vehicles (LDGVs) in Table 3-7, for light-duty gasoline-fueled trucks (LDGTs) with gross vehicle weight ratings (GVWR) of 6,000 lbs or less (LDGT1s) in Table 3-8, for LDGTs with GVWR of 6,001 lbs and up (LDGT2s) in Table 3-9, and for heavy-duty gasoline-fueled vehicles (HDGVs) in Table 3-10.

Tables 3-11 through 3-14 present nationwide fleet exhaust, evaporative, refueling, and total HC emission factors, respectively. These factors also include the contributions of diesel-powered vehicles, appropriately weighted by vehicle miles traveled (VMT) fractions. Since the controls on in-use gasoline volatility that are evaluated in this analysis would have no impact on hydrocarbon emissions from diesel vehicles, the diesel vehicle emission factors that are weighted into the fleetwide factors are those calculated using standard MOBILE3 inputs.[1] The VMT fractions used for the different vehicle categories and for urban and rural travel are those developed using EPA's MOBILE3 Fuel Consumption Model (M3FCM), which is further discussed in the following section.[10]

All of the hydrocarbon emission factors for gasoline-fueled vehicles presented below include the assumption that an onboard refueling emission control requirement will be effective in 1990 and later model years. Emission factors have also been calculated under the assumption that no onboard refueling controls will be required. These factors, which were used in the sensitivity and economic analyses, are not reproduced here.

B. Calculation of Inventories

Calculation of emission inventories for each of the projection years is necessary in order to estimate the emission reductions resulting from various control strategies, and as input for the ozone air quality modeling. A "No RVP Control"

Table 3-6

Populations of the 61 Non-California Urban Non-Attainment Areas Used in Calculation of Nationwide Emission Factors

MSA/CMSA Name	Population (1980 Census)
New York Metro Area	17 190 221
Chicago Metro Area	7 794 851
Philadelphia Metro Area	4 716 818
Detroit MI	4 488 072
Boston Metro Area	4 136 612
Washington DC-MD-VA	3 250 822
Dallas-Fort Worth TX	2 930 516
Houston TX	2 735 766
Pittsburgh PA	2 218 870
Greater CT Metro Area	2 206 318
Baltimore MD	2 199 531
Atlanta GA	2 138 231
Cleveland OH	1 898 825
St Louis MO	1 808 621
Cincinnati Metro Area	1 660 278
Miami-Hialeah FL	1 625 781
Denver-Boulder CO	1 618 461
Tampa-St. Petersburg-Clearwater FL	1 613 603
Phoenix AZ	1 509 052
Milwaukee Metro Area	1 498 078
Kansas City MO-KS	1 433 458
New Orleans LA	1 256 256
Indianapolis IN	1 166 575
San Antonio TX	1 071 954
Charlotte-Gastonia-Rock Hill NC-SC	971 391
Louisville KY	956 756
Dayton-Springfield OH	942 083
Memphis TN	913 472
Salt Lake City-Ogden VT	910 222
Birmingham AL	883 946
Nashville TN	850 505
Richmond-Petersburg VA	761 311
Scranton-Wilkes-Barre PA	728 796

Table 3-6
(continued)

MSA/CMSA Name	Population (1980 Census)
Akron OH	660 328
Tulsa OK	657 173
Allentown-Bethlehem PA	635 481
Providence RI	618 514
Grand Rapids MI	601 680
Harrisburg-Lebanon-Carlisle PA	555 158
Springfield MA	515 259
Baton Rouge LA	494 151
El Paso TX	479 899
Chattanooga TN	426 540
Canton OH	404 421
Worcester MA	402 918
York PA	381 255
Beaumont-Port Arthur TX	375 497
Lancaster PA	362 346
Huntington-Ashland WV	336 410
Reading PA	312 509
Erie PA	279 780
Atlantic City NJ	276 385
Galveston-Texas City TX	195 940
Portland ME	193 831
Portsmouth-Dover-Rochester NH-ME	190 938
Brazoria TX	169 587
Lake Charles LA	167 223
New Bedford MA	166 699
Muskegon MI	157 589
Longview-Marshall TX	151 752
Vineland-Millville-Bridgeton NJ	132 866

Table 3-7

Weighted National Average Total HC Emission Factors -- LDGVs (g/mi)

Strategy (RVP, in psi)	1983	Projection Year 1990	1995	2000	2010
No RVP Control	5.03	2.70	1.94	1.72	1.68
11.5		2.50	1.55	1.20	1.07
11.0		2.29	1.44	1.14	1.04
10.5		2.11	1.34	1.09	1.01
10.0		1.98	1.27	1.05	0.99
9.5		1.88	1.21	1.02	0.97
9.0		1.79	1.16	0.99	0.95
8.5		1.76	1.14	0.97	0.93
8.0		1.72	1.11	0.95	0.92

Table 3-8

Weighted National Average Total HC Emission Factors -- LDGT1s (g/mi)

Strategy (RVP, in psi)	1983	Projection Year 1990	1995	2000	2010
No RVP Control	7.08	4.40	3.04	2.32	2.10
11.5		4.20	2.70	1.87	1.56
11.0		3.98	2.57	1.80	1.53
10.5		3.79	2.45	1.73	1.49
10.0		3.64	2.36	1.68	1.46
9.5		3.52	2.29	1.63	1.43
9.0		3.42	2.22	1.58	1.40
8.5		3.36	2.18	1.55	1.37
8.0		3.32	2.14	1.52	1.35

Table 3-9

Weighted National Average Total HC Emission Factors -- LDGT2s (g/mi)

Strategy (RVP, in psi)	1983	Projection Year 1990	1995	2000	2010
No RVP Control	10.03	5.42	3.37	2.36	2.15
11.5		5.19	3.03	1.93	1.62
11.0		4.92	2.88	1.85	1.58
10.5		4.68	2.75	1.79	1.55
10.0		4.48	2.64	1.73	1.51
9.5		4.31	2.55	1.69	1.49
9.0		4.15	2.47	1.64	1.46
8.5		4.03	2.41	1.61	1.43
8.0		3.93	2.35	1.58	1.41

Table 3-10

Weighted National Average Total HC Emission Factors -- HDGVs (g/mi)

Strategy (RVP, in psi)	1983	Projection Year 1990	1995	2000	2010
No RVP Control	14.63	7.94	5.68	5.03	4.77
11.5		7.63	4.88	4.09	3.78
11.0		7.21	4.71	3.99	3.71
10.5		6.83	4.56	3.89	3.63
10.0		6.51	4.42	3.80	3.57
9.5		6.23	4.29	3.72	3.50
9.0		5.97	4.17	3.64	3.43
8.5		5.77	4.07	3.56	3.37
8.0		5.58	3.98	3.49	3.31

Table 3-11

Weighted National Average Exhaust HC Emission Factors -- All Vehicles (g/mi)

Strategy (RVP, in psi)	1983	Projection Year			
		1990	1995	2000	2010
No RVP Control	3.60	1.63	1.12	0.96	0.93
11.5		1.62	1.09	0.90	0.86
11.0		1.61	1.08	0.90	0.86
10.5		1.59	1.07	0.90	0.86
10.0		1.58	1.06	0.89	0.86
9.5		1.57	1.06	0.89	0.86
9.0		1.55	1.05	0.89	0.86
8.5		1.55	1.05	0.89	0.86
8.0		1.55	1.05	0.89	0.86

Table 3-12

Weighted National Average Evaporative HC Emission Factors -- All Vehicles (g/mi)

Strategy (RVP, in psi)	1983	Projection Year 1990	1995	2000	2010
No RVP Control	2.08	1.36	1.02	0.89	0.86
11.5		1.19	0.71	0.51	0.43
11.0		1.01	0.62	0.46	0.40
10.5		0.86	0.54	0.42	0.37
10.0		0.76	0.49	0.38	0.35
9.5		0.67	0.44	0.35	0.33
9.0		0.61	0.40	0.33	0.31
8.5		0.57	0.37	0.30	0.29
8.0		0.54	0.35	0.28	0.27

Table 3-13

Weighted National Average Refueling HC Emission Factors -- All Vehicles (g/mi)

Strategy (RVP, in psi)	1983	Projection Year 1990	1995	2000	2010
No RVP Control	0.36	0.27	0.13	0.06	0.03
11.5		0.27	0.13	0.06	0.03
11.0		0.26	0.12	0.06	0.03
10.5		0.25	0.12	0.06	0.03
10.0		0.24	0.11	0.05	0.03
9.5		0.22	0.11	0.05	0.03
9.0		0.21	0.10	0.05	0.03
8.5		0.20	0.10	0.05	0.03
8.0		0.19	0.09	0.05	0.03

Table 3-14

Weighted National Average Total HC Emission Factors -- All Vehicles (g/mi)

Strategy (RVP, in psi)	1983	Projection Year 1990	1995	2000	2010
No RVP Control	6.04	3.27	2.26	1.91	1.83
11.5		3.08	1.92	1.47	1.32
11.0		2.88	1.82	1.42	1.29
10.5		2.71	1.73	1.37	1.26
10.0		2.57	1.66	1.33	1.24
9.5		2.46	1.60	1.30	1.22
9.0		2.37	1.55	1.26	1.19
8.5		2.32	1.52	1.24	1.17
8.0		2.28	1.49	1.22	1.16

case is developed in which no additional emission controls beyond those already implemented are assumed to be in effect. Comparison of projected inventories under this base case to those projected under different control cases provides estimated emission reductions.

Inventories for the projection years under the "No RVP Control" case and the various control cases under consideration are also a key input for the ozone non-attainment analysis. EPA used the Empirical Kinetic Modeling Approach (EKMA) to estimate the ambient ozone concentrations in the urban ozone non-attainment areas evaluated in this analysis. This is discussed in the section I.C., below.

Projection of emission inventories requires that a base-year inventory (1983 for this analysis) be supplied, along with base-year ozone design values (ambient concentrations, expressed in parts per million (ppm)), and assumptions describing future growth and anticipated emission reductions for each component of the inventory.

The inventory is divided into mobile and stationary source subtotals, each of which in turn is further divided into a number of individual source categories. This section of the chapter describes the base-year emissions inventory, the growth rates and controls assumed in the projection of future emission inventories, and the other inputs to the EKMA for the ozone non-attainment analysis. These are followed by sections presenting the results of the nationwide emissions analysis and the ozone air quality (EKMA) analysis.

1. Base Year (1983) Emissions Inventory

The base-year non-methane hydrocarbon (NMHC) emissions inventory used for these analyses is for calendar year 1983, the most recent year for which official design values were available at the time of this analysis. This base-year inventory is based on that developed by EPA's National Air Data Branch within the Office of Air Quality Planning and Standards (OAQPS), and is referred to as the NEDS (National Emissions Data System) inventory.

Table 3-15 presents the nationwide base year inventory used in this analysis, and Table 3-16 presents the base year inventory for the 61 non-California urban non-attainment areas analyzed. The differences between the inventories taken from NEDS and the inventories presented in Tables 3-15 and 3-16 involve the gasoline-related stationary source and the mobile source components. These adjustments are described below. More detailed information on the adjustments to the inventory is available in an EPA technical memorandum.[3]

Table 3-15

Base Year (1983) Nationwide NMOC Emissions Inventory

Source Category	NMOC Emissions (x 1000 T)
Light-Duty Vehicles (LDV)	5946.3
Light-Duty Trucks (LDT)	2686.4
Heavy-Duty Gasoline-Fueled Vehicles (HDGV)	868.2
Heavy-Duty Diesel-Powered Vehicles (HDDV)	486.4
Off-Highway Vehicles*	1209.5
Stage I	252.5
Remainder (Bulk Storage)	446.9
Area Sources*	9340.7
Point Sources*	2188.8
Mobile Source Subtotal	11196.8
Stationary Source Subtotal	12228.9
Gasoline-related Subtotal**	10200.3
Non-gasoline-related Subtotal**	13225.4
TOTAL EMISSIONS	23425.7

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* The components of these categories are described in the text.

** Gasoline-related = LDV + LDT + HDGV + Stage I + Remainder; non-gasoline-related = HDDV + Off-highway + Area + Point.

Table 3-16

Base Year (1983) NMOC Emissions Inventory for 61 Non-California Urban Ozone Non-Attainment Areas

Source Category	NMOC Emissions (x 1000 T)
Light-Duty Vehicles (LDV)	2332.9
Light-Duty Trucks (LDT)	752.7
Heavy-Duty Gasoline-Fueled Vehicles (HDGV)	300.6
Heavy-Duty Diesel-Powered Vehicles (HDDV)	184.0
Off-Highway Vehicles*	311.5
Stage I	101.4
Remainder (Bulk Storage)	181.2
Area Sources*	2815.4
Point Sources*	915.1
Mobile Source Subtotal	3881.7
Stationary Source Subtotal	4013.1
Gasoline-related Subtotal**	3668.8
Non-gasoline-related Subtotal**	4226.0
TOTAL EMISSIONS	7894.7

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* The components of these categories are described in the text.

** Gasoline-related = LDV + LDT + HDGV + Stage I + Remainder; non-gasoline-related = HDDV + Off-highway + Area + Point.

The NEDS base-year inventories for light-duty vehicles (LDVs), light-duty trucks (LDTs), and heavy-duty gasoline-fueled vehicles (HDGVs) were adjusted to account for city-specific data on temperatures, market penetration of alcohol-blend fuels, and in-use volatility, as described in sections I.A.1., 2., and 3. of this chapter, respectively. This adjustment consisted of multiplying the NEDS inventories for each vehicle class by the ratio of the emission factors incorporating the city-specific input data to the emission factors using standard input data, which are used by NEDS. These inventories, as well as that for heavy-duty diesel vehicles (HDDVs), are also based on the vehicle miles traveled (VMT) data from the MOBILE3 Fuel Consumption Model (M3FCM) rather than on NEDS' VMT data.[10] This adjustment is performed by multiplying the inventories by the ratio of the 1983 M3FCM VMT to the NEDS VMT.

The other significant change is in the Stage I and Remainder (bulk storage) categories' inventories. As described in section I.B.3. of this chapter, the base-year inventories for these categories are based on information developed in EPA's response to comments received on the gasoline marketing study.[11]

The categories of concern in this analysis are, of course, those directly related to gasoline. As listed in Tables 3-15 and 3-16, these are LDVs, LDTs, HDGVs, Stage I, and Remainder (bulk storage). Emissions from HDDVs are included in the mobile source emissions totals, but not as gasoline-related emissions. The "off-highway" mobile source category, which also is assumed not to be gasoline-related, consists of emissions from aircraft, locomotives, inboard- and outboard-powered vessels, small general-utility engines, agricultural and heavy-duty construction equipment, and snowmobiles. The bulk of these sources are unregulated and are not gasoline-fueled. More information on these sources and their emissions is available in the most recent AP-42 document.[1]

The vast majority of stationary source emissions are in the categories shown in Tables 3-15 and 3-16 as "Area" and "Point" sources. These categories include a number of industrial processes (e.g., manufacture of plastic and rubber products, polymers, resins, synthetic fibers, pharmaceutical products), many industrial surface coating processes (e.g., large appliances, various metal products, large ships and aircraft), the use of solvents (e.g., dry cleaning, adhesives, degreasing, graphic arts), and other miscellaneous sources (e.g., solid waste disposal, open forest and agricultural burning). For these many stationary sources, 1983 NEDS inventories are used in this analysis. None of these "area" and "point" source emissions will be affected by gasoline volatility controls.

2. Mobile Source VMT Growth Rates and Emission Controls

Given the base-year inventories for the various mobile source categories, future inventories are projected using assumptions about anticipated VMT growth rates and emission controls. The emission factors calculated by MOBILE3 and presented in the previous section incorporate the effects of the existing mobile source emission control program (i.e., fleet turnover leading to replacement of older vehicles with later-model vehicles subject to more stringent emission standards). The "No RVP Control" emission factors shown in Tables 3-7 through 3-14 assume continuance of the existing mobile source control program; the various RVP control scenarios include the effects of both the existing program and various levels of in-use and certification fuel volatility (RVP) control.

In all of these cases, the existence of vehicle inspection and maintenance (I/M) programs is assumed for all ozone non-attainment areas. As noted previously, these emission factors also assume implementation of onboard (vehicle-based) controls on refueling emissions, beginning in the 1990 model year.

The growth assumed for the LDV, LDT, HDGV, and HDDV categories is based on the urban VMT projections from the MOBILE3 Fuel Consumption Model (M3FCM).[10] The VMT for the projection years is calculated by the M3FCM by applying an annual compound VMT growth rate to the base-year VMT. Projected VMT by category and projection year, based on the M3FCM, are summarized in Table 3-17.

Another factor that has an important influence on the mobile source emission projections is the division of VMT into urban and rural fractions and the growth rates assumed to be applicable to urban VMT. In the NEDS base-year mobile source inventories, fleet emission factors are based on urban and rural VMT breakdowns for only four vehicle categories (LDV, LDT, HDGV, and HDDV). Thus, the M3FCM VMT projections, which are calculated for seven vehicle categories (LDGV, LDDV, LDGT1, LDGT2, LDDT, HDGV, and HDDV), are weighted to correspond to these categories. These weightings are then used with in the adjustment of the base-year inventories.

In this analysis about 54.6 percent of total 1983 nationwide VMT is urban VMT, while in the 61 urban areas modeled about 81.7 percent of total 1983 VMT is urban.[3] For both the nationwide and urban area analyses, the urban VMT fraction is assumed to increase by 0.358 percent annually. The base-year NEDS inventories for the mobile source categories were adjusted using fleetwide emission factors that reflect

Table 3-17

Annual VMT by Vehicle Class (x 10^9 mi)

Year	Vehicle Class LDV	LDT	HDGV	HDDV	TOTAL*
1983	1031.80	341.01	55.45	97.48	1525.74
1990	1187.53	397.67	55.17	120.44	1760.81
1995	1298.75	438.60	55.93	137.81	1931.08
2000	1409.98	479.29	58.70	154.28	2102.25
2010	1632.44	560.23	68.21	182.83	2443.71

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* Class VMTs may not add exactly to totals due to rounding.

this urban/rural division of VMT and urban VMT growth rate. More information on urban/rural VMT breakdowns, urban VMT growth, and the resulting adjustment to the base-year inventory is provided in reference [3].

3. Stage I and Remainder Growth Rates and Controls

The impacts of in-use RVP control on Stage I and Remainder (bulk storage) emissions were discussed in section II.C. of Chapter 2. This section discusses three other aspects of the modeling of these emissions: the base-year inventories used, future growth rates assumed applicable to these categories, and emission reductions expected to occur as a result of additional application of control technology to these sources (excluding RVP control).

The base-year emissions inventories for Stage I and bulk storage were taken from EPA's Response to Comments to the Gasoline Marketing Study, with a few minor adjustments that are described below.[11] These inventories, which are referred to in this section as the "GEMS inventories" (to distinguish them from the NEDS inventories used for other stationary sources), were presented in reference [11] in terms of thousands of megagrams (x 1000 Mg) for the year 1984. In addition, these inventories assume an average summertime RVP of 11.5 psi. Each of these results in an adjustment to the GEMS inventories being required before substituting them for the corresponding NEDS inventories.

These inventories were adjusted from the 11.5 psi RVP used in the gasoline marketing analysis to 11.0 psi RVP, which is the population-weighted national average RVP for 1983 used in this analysis (see section I.A.3. of this chapter). An adjustment was also made to base the inventories on 1983, the base year of this analysis, rather than 1984 as presented in reference [11]. The adjustment factor for changing the base year is the ratio of fuel consumption in 1983 to fuel consumption in 1984, using fuel consumption results from the MOBILE3 Fuel Consumption Model.[10] The use of fuel consumption to model growth in these emissions rests on the idea that gasoline storage and distribution losses should be directly proportional to total gasoline throughput, all other factors being constant. This is also discussed under growth rates, below.

The resulting base year inventories for these categories are 252,500 tons from Stage I and 446,900 tons from bulk storage. These figures are included in the base-year nationwide nationwide inventories on which future projections are based. The city-specific base-year emissions inventories for these two categories were developed by adjusting the corresponding city-specific NEDS inventories in the same way.

The growth rates used to model future Stage I and Remainder inventories are based on fuel consumption projections from the MOBILE3 Fuel Consumption Model. Previous modeling of these categories has generally assumed positive annual growth rates based on economic growth projections for large sectors of the economy. However, Stage I and Remainder emissions logically are more a function of total gasoline throughput (and thus of total gasoline consumption) than of general economic growth. Therefore, in addition to substituting the "GEMS" Stage I and Remainder inventories for those supplied by NEDS, growth rates derived from MOBILE3 Fuel Consumption Model projections of total gasoline consumption are used for these categories.

The fuel consumption projections used predict that gasoline consumption will gradually decline through the remainder of this century, from base-year consumption of about 94.16 x 10^9 gallons in 1983 to about 74.73 x 10^9 gallons in 2000. Projected gasoline consumption reaches a minimum of about 74.51 x 10^9 gallons in 2002, after which it is predicted to slowly increase, to about 78.63 x 10^9 gallons in 2010. Thus, the growth rate applied to Stage I and Remainder emissions is negative through 2002, then positive through 2010.

The net effect of the use of GEMS inventories and MOBILE3 Fuel Consumption Model-based growth rates on the Stage I and Remainder categories is to reduce these emission considerably, both in absolute terms and as a fraction of total NMHC emissions, relative to the levels included in the original volatility study.[12]

4. Stationary Source Growth Rates and Controls

Since Stage I and Remainder emissions have been handled separately in this analysis, the remaining stationary sources of NMHC emissions are the "Area" and "Point" categories of Tables 3-15 and 3-16. The distinction between the area and point categories is made on the basis of annual emission totals, with smaller individual emission sources designated as "area" and larger sources as "point."

There are many individual contributors to area and point source NMHC emissions. They can broadly be classified as emissions from industrial manufacturing processes (e.g., plastic and rubber products, polymers and resins, etc.), emissions from surface coating operations (e.g., of large appliances, ships, and airplanes), and miscellaneous sources (e.g., open burning and solid waste disposal). These numerous categories share in common the fact that they are not gasoline-related, and thus that emissions from these sources will be unaffected by any RVP controls.

The emissions inventories from these categories for the base year were taken from the 1983 NEDS inventory. These inventories are shown for the nation in Table 3-15 and for the 61 non-California urban non-attainment areas in Table 3-16. Growth and replacement rates applied to these categories are based on information supplied by EPA's Office of Air Quality Planning and Standards, and are described briefly here.

As noted above, there are many individual sources included in the "area" and "point" categories of this analysis. The annual growth rate applied to industrial manufacturing processes, industrial surface coating operations, and other solvent uses are 3.3, 3.1, and 0.8 percent, respectively. These rates are applied to the relevant emission sources listed under both area and point sources. Remaining point sources (not included in the three sub-categories noted above) are assumed to increase by 1.9 percent annually, and area sources not covered by these three sub-categories have no growth assumed.

Regardless of whether in-use RVP control is implemented, EPA, states, and local areas have established equipment-related controls for stationary sources that must be accounted for in modeling future hydrocarbon emissions. The Clean Air Act as amended in 1977 requires that hydrocarbon emissions from both new and existing stationary sources in ozone non-attainment areas be controlled to the lowest achievable levels. EPA has interpreted this as those levels achievable with RACT, which varies from source to source.

To assist the states in developing control regulations consistent with RACT levels, EPA's Office of Air Quality Planning and Standards (OAQPS) issued a series of control technique guideline (CTG) documents relevant to various sources. These CTGs assessed the technology available to control HC emissions from various sources, and provided estimates of the emission rates achievable with the full implementation of RACT-based controls.

The Clean Air Act Amendments of 1977 also stated that all areas were to be in compliance with the ozone National Ambient Air Quality Standard (NAAQS) by December 31, 1982; therefore, this date was originally projected as the year by which RACT levels of control would be fully implemented on sources in the non-attainment areas of the late 1970s and early 1980s. In the 1985 volatility study, EPA made certain assumptions regarding the rate at which RACT-based emission controls would be implemented; essentially, the assumption was that one to five percent of the emission reductions available through the application of RACT controls were in effect as of 1982 (the base year used in that analysis), and that all remaining available controls would be implemented by 1988.[12] This resulted in the highest projections of future emission reductions expected to result from additional implementation of RACT and the lowest projected ozone values.

EPA's earlier assumptions regarding the degree to which RACT-based controls have already been applied and the extent of emission reductions still available from further RACT application were erroneous. EPA's current best estimates indicate that, while RACT-based emission reductions have already been achieved from some stationary sources, further reductions are still available from other components of the stationary source inventory.

Specifically, the modeling now assumes that no further emission reductions can be obtained through the implementation of RACT controls on area source solid waste disposal, miscellaneous area sources, or other solvent use (i.e., solvent use other than industrial surface coating operations). CTGs yet to go into effect are assumed to yield reductions amounting to two percent of the total 1983 emission inventory, from these components of the stationary source inventory: Stage I and remainder (bulk storage), petroleum refineries, industrial processes (mostly chemical manufacturing), and industrial surface coating operations. A reduction of two percent in the total inventory is equivalent to a 12 percent reduction from these specific sources. Compared to the previous analysis, these assumptions result in smaller reductions being obtained through RACT, and greater projected inventories for the affected stationary source categories.

EPA is continuing to evaluate the entire issue of RACT control implementation for stationary sources as part of the Agency's efforts to comprehensively address ozone control strategies; however, the assumptions made in this analysis represent the best estimate at this time.

Replacement rates refer to the projected replacement of older (i.e., higher emission) equipment and facilities by newer (i.e., low emission) equipment and facilities. Emission reductions due to application of RACT apply to such older equipment (see below), while the newer replacement equipment is subject to new source performance standards (NSPS). In this analysis, emissions from a given source under full implementation of RACT are assumed to be equal to emissions from a replacement for that source subject to NSPS; therefore, the replacement rates used do not affect projected emissions from stationary sources.

C. EKMA: Ozone Air Quality Analysis

The ozone air quality analysis for this study was conducted using the Empirical Kinetic Modeling Approach (EKMA). EKMA uses projected future emission inventories and other input data to estimate ambient ozone concentrations, NAAQS compliance status, and numbers of expected exceedances for specific urban areas future years. Additional EKMA input data are described below. The results of the EKMA modeling are presented in section III of this chapter.

1. Background Ambient Ozone Concentration

One of the inputs to EKMA is the background ozone level. This is an estimate of the ambient ozone concentration that would exist as a result of naturally occurring emissions of ozone precursors, in the absence of the anthropogenic (man-made) emissions included in the inventory modeling. Previous analyses, including those performed as part of the original volatility study, have assumed no background ozone concentration. This analysis has been revised to incorporate the assumption of a 0.07 parts per million (ppm) background ozone concentration, reflecting EPA's current best estimate.

2. NMOC:NOx Ratios

Another input required for the EKMA model to project future ambient ozone concentrations is the ratio of non-methane hydrocarbon (NMHC) emissions to oxides of nitrogen (NOx) emissions, or the NMHC:NOx ratio. Since much of the inventory from stationary sources is composed of photochemically reactive volatile organic compounds (VOC) that are not hydrocarbons, this ratio is also referred to as the non-methane organic compound (NMOC)-to-NOx ratio.

The NMOC:NOx ratios used in these analyses are based on the average of the median ratios observed in 1984 and 1985, for those cities where data for both years were available. For cities where data from only one of the years were available, that value is used. The ratios used in these analyses were obtained from EPA's Office of Air Quality Planning and Standards (OAQPS), and are summarized in Table 3-18.[13]

Table 3-18

NMOC:NOx Ratios Used in Air Quality Modeling [1]

MSA/CMSA Name	NMOC:NOx Ratio
Akron, OH	12.7
Atlanta, GA	10.4
Baton Rouge, LA	14.9
Beaumont-Port Arthur, TX [2]	33.0
Birmingham, AL	11.7
Boston Metro Area	7.6
Charlotte-Gastonia-Rock Hill, NC-SC [3]	10.4
Chattanooga, TN	16.8
Cincinnati Metro Area	9.1
Cleveland, OH	7.5
Dallas-Fort Worth, TX [4]	12.8
El Paso, TX	13.5
Galveston-Texas City, TX [5]	33.2
Houston, TX	12.9
Indianapolis, IN	11.3
Kansas City, MO-KS	9.3
Lake Charles, LA	24.3
Memphis, TN	13.9
Miami-Hialeah, FL [6]	13.3
Philadelphia, PA [7]	8.1
Portland, ME	11.6
Richmond-Petersburg, VA [8]	10.9
Scranton-Wilkes-Barre, PA [9]	14.3
St. Louis, MO-IL	9.6
Washington, DC-MD-VA	9.0

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[1] NMOC:NOx ratio of 11.6 used for cities not listed.
[2] Beaumont observations.
[3] Charlotte observations.
[4] Average of Dallas and Ft. Worth observations.
[5] Texas City observations.
[6] Miami observations.
[7] Average of observations from 2 sites, both in 1985.
[8] Richmond observations.
[9] Wilkes-Barre observations.

Only 25 of the 61 non-California urban ozone non-attainment areas are listed in Table 3-18. For those cities not shown, a default NMOC:NOx ratio of 11.6 is used.[13] This value is based on the median of both year's observations for all of the cities listed with the exception of Beaumont-Port Arthur and Galveston-Texas City. These areas are not included in determining the median, and thus the default value, since their NMOC:NOx ratios are extremely high due to intense concentrations of petroleum processing facilities in these areas, and thus are not indicative of the rest of the country.

3. Ozone Design Values

As was noted earlier, the inventory projections and air quality analyses in this chapter use 1983 as the base year. The 1983 design values are based on air quality monitoring data recorded in 1982, 1983, and 1984. These design values, which are shown in Table 3-19 under the heading "82-84 design values," are the basis for determining which urban areas are in non-attainment status for the ozone NAAQS. They are based on the 1982, 1983, and 1984 monitoring data without modification. In other words, the values shown in Table 3-19 under the heading "82-84 design values" represent the fourth highest one-hour ambient ozone concentrations measured in the three years of monitoring data examined.

Previous ozone air quality analyses have used design values determined in this way directly as input for EKMA. However, the air quality analyses for this chapter include a refinement which leads to the development of a second set of "design values" being used to represent the base year ambient concentrations. These values are also shown in Table 3-19, under the heading "EKMA design values."

This second set of design values reflect modifications that take into account the transport of ozone. This is accomplished by a computer program known as MASH (Multiple Airshed). MASH uses wind directions and the times that ozone exceedances (i.e., one-hour concentrations in excess of the 0.12 ppm NAAQS) occur to determine whether an exceedance is predominantly the result of emissions originating in the local area, or of emissions originating in a nearby major metropolitan area upwind. It then assigns the measured ozone levels to either the upwind metropolitan area or the local area as a function of selected criteria.[14] In regions where ozone transport is significant (e.g., the northeastern part of the country), this process tends to lower the design values in smaller cities or MSAs and to raise the design values in the larger metropolitan areas. These MASH-processed design values

Table 3-19

61 Non-California Urban Ozone Non-Attainment Areas and Associated Design Values (ppm)

Area	82-84 Design Values	EKMA Design Values
EPA Region 1		
Boston Metro Area	0.19	0.18
Greater Connecticut Metro Area	0.23	0.18
New Bedford, MA	0.19	0.19
Portland, ME	0.15	0.10
Portsmouth-Dover-Rochester, NH-ME	0.13	0.09
Providence, RI	0.16	0.15
Springfield, MA	0.19	0.17
Worcester, MA	0.14	0.12
EPA Region 2		
Atlantic City, NJ	0.19	0.15
New York Metro Area	0.23	0.24
Vineland-Millville-Bridgeton, NJ	0.14	0.14
EPA Region 3		
Allentown-Bethlehem, PA	0.15	0.14
Baltimore, MD	0.17	0.17
Erie, PA	0.13	0.13
Harrisburg-Lebanon-Carlisle, PA	0.13	0.13
Lancaster, PA	0.14	0.09
Philadelphia Metro Area	0.18	0.20
Pittsburgh, PA	0.14	0.14
Reading, PA	0.13	0.13
Richmond-Petersburg, VA	0.14	0.14
Scranton-Wilkes Barre, PA	0.13	0.13
Washington, DC-MD-VA	0.16	0.17
York, PA	0.13	0.13
EPA Region 4		
Atlanta, GA	0.17	0.17
Birmingham, AL	0.15	0.15
Charlotte-Gastonia-Rock Hill, NC-SC	0.13	0.13
Chattanooga, TN-GA	0.13	0.13
Huntington-Ashland, WV-KY-OH	0.14	0.14
Louisville, KY-IN	0.15	0.15
Memphis, TN-AR-MS	0.13	0.13
Miami-Hialeah, FL	0.13	0.13
Nashville, TN	0.13	0.13
Tampa-St. Petersburg-Clearwater, FL	0.13	0.13

Table 3-19 (cont'd)

Area	82-84 Design Values	EKMA Design Values
EPA Region 5		
Akron, OH	0.13	0.13
Canton, OH	0.13	0.13
Chicago Metro Area	0.20	0.25
Cincinnati Metro Area	0.15	0.17
Cleveland, OH	0.14	0.14
Dayton-Springfield, OH	0.13	0.13
Detroit, MI	0.14	0.14
Grand Rapids, MI	0.13	0.13
Indianapolis, IN	0.13	0.13
Milwaukee Metro Area	0.17	0.17
Muskegon, MI	0.14	0.14
EPA Region 6		
Baton Rouge, LA	0.17	0.17
Beaumont-Port Arthur, TX	0.21	0.21
Brazoria, TX	0.14	0.14
Dallas-Fort Worth, TX	0.16	0.16
El Paso, TX	0.17	0.17
Galveston-Texas City, TX	0.17	0.17
Houston, TX	0.25	0.25
Lake Charles, LA	0.15	0.15
Longview-Marshall, TX	0.15	0.15
New Orleans, LA	0.15	0.15
San Antonio, TX	0.14	0.14
Tulsa, OK	0.13	0.13
EPA Region 7		
Kansas City, MO-KS	0.14	0.14
St. Louis, MO-IL	0.17	0.17
EPA Region 8		
Denver-Boulder, CO	0.14	0.14
Salt Lake City-Ogden, UT	0.15	0.15
EPA Region 9		
Phoenix, AZ	0.15	0.15

are intended for use in ozone air quality modeling for Regulatory Impact Analyses (RIAs), and are not appropriately used in determining attainment/non-attainment status for individual areas.

It should also be noted that there is relatively little difference in the two sets of design values, with the "82-84 design value" and "EKMA design value" being equal for 46 of the 61 areas modeled. Of the 15 areas where the application of the MASH program led to a change in the design value, the value used for input to EKMA is lower than the unmodified value in 10 of the areas and higher in five of them. The areas with differences between the two values are concentrated in the Northeast and along the central East Coast (EPA Regions 1, 2, and 3), where many of the MSAs and CMSAs are contiguous. The greatest increase in design value resulting from the MASH program occurs for the Chicago Metropolitan Area. The increase of 0.05 ppm represents a 25 percent increase over the unmodified value, reflecting the fact that some of the ozone-precursor emission inventory generated in this area is transported downwind before it is photochemically converted to ozone.

II. Nationwide and Non-Attainment Area Inventory Projections

This section presents the results of the nationwide emissions inventory projections, as well as inventory projections for the 61 non-California urban non-attainment areas. Projected emission inventories have two purposes in this study. First, the inventories are used to generate the projected emissions reductions associated with each control strategy, which in turn are used to relatively rank the control effectiveness and cost-effectiveness of these and other control programs. Second, the emission inventories are used as input for the ozone air quality modeling. In neither case is a true annual inventory desirable or appropriate. Ozone is predominantly a summer problem, so projected emissions in the winter are of less utility than are those in the summer. In addition, ozone modeling is performed on a single-day basis (the design value day), so the emission projection for that day is most appropriate. Since projections of ozone attainment hinge on whether the projected ambient ozone concentration on that day is above or below the standard, the relative ranking of programs should depend on their effectiveness not only during the summer, but especially on the days of highest ozone production (e.g., the design value day).

In fact, both purposes are served using the "annual" inventories presented below. The "annual" inventories are derived by multiplying emission factors based on design value day conditions by annual activity rates (i.e., VMT). Thus, while the inventories are expressed in units of tons/year, they are more accurately thought of as design value day inventories times 365. This is why annual reductions can appropriately be generated for 5-month in-use RVP control. While the emission factors for non-fuel-related sources may not be specific to the design value day, they generally are summer (and thus comparable) figures.

Thus, though "annual" inventories are used as input for EKMA, daily inventories are effectively being used. For control and cost-effectiveness ranking, it does not matter whether a daily or an annual figure is used provided that the same period is used for all sources and the same fraction of each source's emission reduction is in the relevant (ozone producing) period.

Inventory projections were also made using mobile source emission factors based on July-average temperatures for the 61 non-attainment areas. The July-average temperatures are more representative of the entire summer control period than are the design value day temperatures, and thus are more relevant to the calculation of economic recovery credits (e.g., recovery and subsequent use of evaporative emissions), which accrue throughout the control period. Only the nationwide inventory projections based on July-average temperatures are presented in this chapter, as their only use is in the nationwide cost-effectiveness analysis.

The projection years for both cases (design value day and July average temperatures) are 1988, 1990, 1992, 1995, 1997, 2000, and 2010. A total of nine regulatory scenarios are presented, ranging from no control (i.e., certification fuel RVP at 9.0 psi, with no regulation of in-use RVP) to eight control scenarios (8.0 to 11.5 psi RVP, in 0.5-psi increments, for both certification and in-use fuel). Changes to the volatility of certification test fuel are modeled as beginning in the 1990 model year. Control of in-use fuel volatility begins in 1988 (for RVP levels down to 10.5 psi), with additional in-use control (to RVP levels of 10.0 psi and lower) beginning in 1992.

The base year (1983) emissions inventories used in the projections were shown in Tables 3-15 and 3-16 for the nation and for the 61 urban areas, respectively, and discussed in the preceding section. All of the necessary inputs describing growth rates and controls on the various source categories were also discussed in the preceding section of this chapter.

The "No Control" scenarios, as discussed under the development of emission factors, assume that in-use RVP will rise to the ASTM recommended limits[9] in those areas where that limit has not yet been reached, and will remain at 1985 levels (see Table 3-5) in those areas where that limit has already been exceeded. The population-weighted national RVP level for the "No Control" cases, calculated in the same way that the nationwide emission factors were calculated (see section I.A.4. of this chapter), is 11.7 psi for ASTM Class C areas.

The "No Control" case and all of the control cases (RVP between 11.5 and 8.0 psi) that are the focus of this analysis assume that onboard refueling emission controls will be required beginning in model year 1990. "No Control" and control projections that do not include onboard refueling controls have also been generated for both the nationwide and 61-area cases. The nationwide inventory projections without onboard are also presented in this section.

The control cases are designated by the RVP level that would apply to certification fuel and to in-use fuel in ASTM Class C areas, which represent much of the country in terms of land area, population, and ozone non-attainment. RVP control levels of 11.5, 11.0, 10.5, 10.0, 9.5, 9.0, 8.5, and 8.0 psi are evaluated. Proportional RVP reductions are assumed for ASTM Class A, B, D, and E areas. The proportional control levels for these areas, corresponding to the listed values for Class C areas, are shown in Table 3-20.

As noted above, the modeling of the urban ozone non-attainment areas is limited to the 61 such areas outside California. The MOBILE3 emission factor model used by EPA is not applicable for California vehicles, which are subject to different emission standards and regulations than are Federal (49-state) vehicles. While the use of nationwide emission factors from the MOBILE3 model only introduces a relatively small error in the nationwide inventories, it is a significant problem when modeling of individual urban areas within California is considered.

A. Nationwide Inventory Projections

The emission inventories presented below, and the ozone air quality projections that follow, are based on phased-in control of in-use fuel volatility, as was stated in the introduction to this section. Due to feasibility considerations, control of in-use volatility can be to levels

Table 3-20

Proportional Reduction Control RVP Levels

	ASTM Class				
	A	B	C	D	E
Current ASTM RVP Limit (psi):	9.0	10.0	11.5	13.5	15.0
Controlled RVP Levels (psi):	6.3	7.0	8.0	9.4	10.4
	6.6	7.4	8.5	10.0	11.1
	7.0	7.8	9.0	10.6	11.7
	7.4	8.3	9.5	11.2	12.4
	7.8	8.7	10.0	11.7	13.0
	8.2	9.1	10.5	12.3	13.7
	8.6	9.6	11.0	12.9	14.3
	9.0	10.0	11.5	13.5	15.0

no lower than 10.5 psi (in ASTM Class C areas) between 1988 and 1991 inclusive. In-use volatility control down to 8.0 psi (in ASTM Class C areas) begins in 1992. Reasons for this two-tiered implementation of in-use control are discussed in Chapter 5. Changes in the volatility of certification test fuel, which will result in vehicle design modifications, are modeled as beginning in the 1990 model year.

Tables 3-21 through 3-24 present the results of the nationwide inventory projections for each of the control scenarios evaluated. Tables 3-21 and 3-22 are based on design value day temperatures, while Tables 3-23 and 3-24 are based on July-average temperatures. Tables 3-21 and 3-23 assume that onboard vehicle refueling emission control systems are already in place, beginning with model year 1990, while Tables 3-22 and 3-24 present the same scenarios without assuming prior implementation of onboard refueling controls. The discussion that follows focuses on the results presented in Table 3-21 and the assumption of onboard control requirements, however, the points made generally are also applicable if Table 3-22 (no onboard requirement) or Tables 3-23 or 3-24 (July-average temperatures) are examined.

The results show that, as would be expected, the lower the level that RVP is controlled to, the greater the reduction in total emissions. Control of in-use fuel RVP to 10.5 psi in 1988 results in total emissions being about 6 percent lower in that year than would occur with no control of volatility. While regulation of in-use fuel volatility in 1988 will not aid areas striving for ozone NAAQS attainment by the December 31, 1987 deadline, this 6 percent reduction in the first year of implementation represents significant and environmentally important control of ozone precursor emissions.

In each of the 3 later projection years (1995, 2000, and 2010), it is clear from Table 3-21 that even a minimal degree of in-use RVP control (to 11.5 psi in ASTM Class C areas), coupled with a change in certification fuel volatility to the same level, yields emission reductions ranging from 4 percent in 1995 to more than 6 percent in 2010. Control of in-use fuel volatility to the current certification fuel level of 9.0 psi provides even more substantial reductions, on the order of 8 to 9 percent. As will be seen in section III of this chapter, reductions of this magnitude provide significant benefits in terms of ambient ozone concentrations and attainment status.

Another observation from the results in Table 3-21 is that the incremental reductions (the reduction in emissions per 0.5 psi decrease in control RVP level in any given projection year)

Table 3-21

Nationwide NMOC Emissions Inventories Assuming Prior Implementation of Onboard Refueling Control in MY 1990

based on design-value temperatures

Control Scenario	NMOC Emissions (x 1000 T/yr) 1990	1995	2000	2010
No RVP Control	20319	19504	19947	22538
RVP = 11.5	19925 (1.9)*	18732 (4.0)	18884 (5.3)	21156 (6.1)
11.0	19481 (4.1)	18481 (5.2)	18739 (6.1)	21060 (6.6)
10.5	19108 (6.0)	18265 (6.4)	18609 (6.7)	20967 (7.0)
10.0	19108** (6.0)	18089 (7.3)	18499 (7.3)	20885 (7.3)
9.5	19108 (6.0)	17949 (8.0)	18409 (7.7)	20815 (7.6)
9.0	19108 (6.0)	17825 (8.6)	18324 (8.1)	20744 (8.0)
8.5	19108 (6.0)	17744 (9.0)	18258 (8.5)	20681 (8.2)
8.0	19108 (6.0)	17672 (9.4)	18198 (8.8)	20620 (8.5)

---

* Figures in parentheses represent percent reduction in inventory relative to "No RVP Control."

** Certification fuel changes in 1990. In-use RVP control to less than 10.5 psi is delayed until 1992 (see Chapter 5).

Table 3-22

Nationwide NMOC Emissions Inventories Assuming No Prior Onboard Refueling Control Requirement

based on design-value temperatures

Control Scenario	NMOC Emissions (x 1000 T/yr) 1990	1995	2000	2010
No RVP Control	20334	19766	20325	22999
RVP = 11.5	19940 (1.9)*	18994 (3.9)	19263 (5.2)	21616 (6.0)
11.0	19496 (4.1)	18731 (5.2)	19100 (6.0)	21499 (6.5)
10.5	19121 (6.0)	18501 (6.4)	18952 (6.8)	21384 (7.0)
10.0	19121** (6.0)	18313 (7.4)	18824 (7.4)	21280 (7.5)
9.5	19121 (6.0)	18160 (8.1)	18715 (7.9)	21190 (7.9)
9.0	19121 (6.0)	18024 (8.8)	18612 (8.4)	21097 (8.3)
8.5	19121 (6.0)	17932 (9.3)	18530 (8.8)	21012 (8.6)
8.0	19121 (6.0)	17848 (9.7)	18452 (9.2)	20929 (9.0)

---

* Figures in parentheses represent percent reduction in inventory relative to "No RVP Control."

** Certification fuel changes in 1990. In-use RVP control to less than 10.5 psi is delayed until 1992 (see Chapter 5).

Table 3-23

Nationwide NMOC Emissions Inventories Assuming Prior Implementation of Onboard Refueling Control in MY 1990

based on July-average temperatures

Control Scenario	NMOC Emissions (x 1000 T/yr)			
	1990	1995	2000	2010
No RVP Control	19687	18975	19443	21974
RVP = 11.5	19425 (1.3)*	18444 (2.8)	18707 (3.8)	21018 (4.4)
11.0	19091 (3.0)	18256 (3.8)	18596 (4.4)	20939 (4.7)
10.5	18796 (4.5)	18083 (4.7)	18490 (4.9)	20860 (5.1)
10.0	18796** (4.5)	17940 (5.5)	18396 (5.4)	20788 (5.4)
9.5	18796 (4.5)	17824 (6.1)	18319 (5.8)	20725 (5.7)
9.0	18796 (4.5)	17719 (6.6)	18244 (6.2)	20661 (6.0)
8.5	18796 (4.5)	17649 (7.0)	18186 (6.5)	20601 (6.2)
8.0	18796 (4.5)	17581 (7.3)	18129 (6.8)	20545 (6.5)

---

* Figures in parentheses represent percent reduction in inventory relative to "No RVP Control."

** Certification fuel changes in 1990. In-use RVP control to less than 10.5 psi is delayed until 1992 (see Chapter 5).

Table 3-24

Nationwide NMOC Emissions Inventories Assuming No Prior Onboard Refueling Control Requirement

based on July-average temperatures

Control Scenario	NMOC Emissions (x 1000 T/yr)			
	1990	1995	2000	2010
No RVP Control	19701	19237	19820	22434
RVP = 11.5	19440 (1.3)*	18706 (2.8)	19086 (3.7)	21480 (4.3)
11.0	19105 (3.0)	18505 (3.8)	18956 (4.4)	21378 (4.7)
10.5	18810 (4.5)	18320 (4.8)	18832 (5.0)	21277 (5.2)
10.0	18810** (4.5)	18166 (5.6)	18721 (5.5)	21183 (5.6)
9.5	18810 (4.5)	18037 (6.2)	18627 (6.0)	21100 (5.9)
9.0	18810 (4.5)	17920 (6.8)	18533 (6.5)	21013 (6.3)
8.5	18810 (4.5)	17836 (7.3)	18457 (6.9)	20932 (6.7)
8.0	18810 (4.5)	17757 (7.7)	18382 (7.3)	20854 (7.0)

---

* Figures in parentheses represent percent reduction in inventory relative to "No RVP Control."

** Certification fuel changes in 1990. In-use RVP control to less than 10.5 psi is delayed until 1992 (see Chapter 5).

are larger in the 11.5-to-9.0 psi range than in the 9.0-to-8.0 psi range. As discussed in section III of Chapter 2, this is primarily because EPA has estimated that no further benefit in terms of exhaust hydrocarbon emissions will result from the control of in-use RVP to levels lower than 9.0 psi in ASTM Class C areas.

Finally, it can also be noted from Table 3-21 that the reductions, in terms of percent relative to no control, increase through the projection period for control scenarios of 11.5, 11.0, and 10.5 psi. These percent reductions are approximately equal in all 3 projection years at the 10.0 psi control level. At 9.5 psi or lower, the percent reductions are greatest for 1995, and are slightly lower in 2000 and again in 2010. Similar trends were reflected in the original volatility study analyses.[12] If long-term RVP control is in the range of 10.5-11.5 psi, vehicle-based control (i.e., increased canister volume) is the dominant effect. There is an inherent delay in the effectiveness of vehicle-based controls, which depend primarily on fleet turnover to achieve the desired reductions in emissions. Thus, this effect increases over time. Fuel control, which is effective immediately, is the dominant effect when long-term RVP control in the 9.5 psi or lower range is examined. The downward trend reflects the continuing conversion of the fleet from carbureted to fuel-injected engines, and the somewhat lower emissions of the latter.

B. Non-Attainment Area Inventory Projections

Much of the discussion of the preceding section, on the nationwide inventory projections, is also applicable to the inventory projections for the 61 non-California urban ozone non-attainment areas. These projections are summarized in Table 3-25.

The most notable difference between the impact of volatility control on the nationwide inventories and the impact on the urban non-attainment area inventories can be seen in the percent reduction estimates associated with each control scenario. For example, control of in-use fuel volatility to 9.0 psi is projected to reduce the nationwide inventory by 8.1 percent in 2000, while the combined inventories for the 61 non-attainment areas would drop by 9.0 percent. Similar differences in the percent reduction obtained from a given control scenario in a specific projection year are apparent when Tables 3-21 and 3-25 are compared cell-by-cell.

The reason that volatility control provides greater proportional reductions in the non-attainment areas than on a

Table 3-25

Total NMOC Emissions for 61 Non-California Urban Ozone Non-Attainment Areas
(Assuming Prior Implementation of Onboard Refueling Control in MY 1990)

Control Scenario	NMOC Emissions (x 1000 T)			
	1990	1995	2000	2010
No RVP Control	6784	6524	6717	7699
RVP = 11.5	6640 (2.1)*	6238 (4.4)	6321 (5.9)	7182 (6.7)
11.0	6476 (4.5)	6145 (5.8)	6266 (6.7)	7147 (7.2)
10.5	6339 (6.6)	6065 (7.0)	6218 (7.4)	7112 (7.6)
10.0	6339** (6.6)	6000 (8.0)	6177 (8.0)	7081 (8.0)
9.5	6339 (6.6)	5948 (8.8)	6144 (8.5)	7055 (8.4)
9.0	6339 (6.6)	5903 (9.5)	6113 (9.0)	7028 (8.7)
8.5	6339 (6.6)	5873 (10.0)	6088 (9.4)	7004 (9.0)
8.0	6339 (6.6)	5846 (10.4)	6065 (9.7)	6983 (9.3)

---

* Figures in parentheses represent percent reduction in emissions, relative to "No RVP Control."

** Certification fuel changes in 1990. In-use RVP control to less than 10.5 psi is delayed until 1992 (see Chapter 5).

nationwide basis can be seen through comparison of the base-year inventories shown in Tables 3-15 and 3-16. Table 3-15 shows that, of the nationwide inventory, 43.5 percent of the total NMOC emissions are from gasoline-related sources. Of the NMOC inventory for the 61 urban areas, 46.5 percent of emissions are from gasoline-related sources. Thus, applying the same proportional reduction to those components of the inventories that would be affected by volatility control (i.e., gasoline-related sources) yields greater reductions, as a fraction of the total inventory, in the 61 urban areas than in the nation taken as a whole.

Figure 3-1 presents the reductions in emissions for the 61 non-California urban ozone non-attainment areas by source. The reductions shown are for RVP control to 9.0 psi, relative to the "No Control" case. As has been noted, only gasoline-related sources will be affected by RVP control; thus, there are no entries on Figure 3-1 for the "area," "point," or "off-highway" source categories. The most important point made clear in Figure 3-1 is that reductions in motor vehicle evaporative emissions account for the bulk of the total reductions in both years. In 1995, the reduction in evaporative emissions represents about 77 percent of the total reduction, and this proportion increases to almost 87 percent of the total in 2010.

III. Ozone Air Quality Analysis

Because of the complex relationship between hydrocarbon emissions and ambient ozone concentrations, the rollback approach used by EPA to model other pollutants (i.e., NOx and CO) is inappropriate for ozone. Instead, EPA uses EKMA (Empirical Kinetic Modeling Approach) to predict future ambient ozone concentrations in urban areas. EKMA utilizes a series of ozone isopleths which depict downwind ozone concentrations as a function of initial NMOC and NOx concentrations, subsequent NMOC emissions, meteorological conditions, reactivity of the precursor mix, and concentrations of ozone and precursors transported from upwind areas.

It should be noted that EKMA as used by EPA is primarily a nationwide-average model. In other words, city-specific information is not generally used as input for the model, with the exception of the base-year ozone concentrations (design values) and NMOC:NOx ratios from which future concentrations are projected. Meteorological conditions (e.g., mixing height, angle of incidence of sunlight) are based on data from one of three cities: Los Angeles, CA, Denver, CO, and St. Louis, MO. The Los Angeles data are used for modeling California coastal cities, and thus are not used in this analysis; Denver data are

Table 3-28

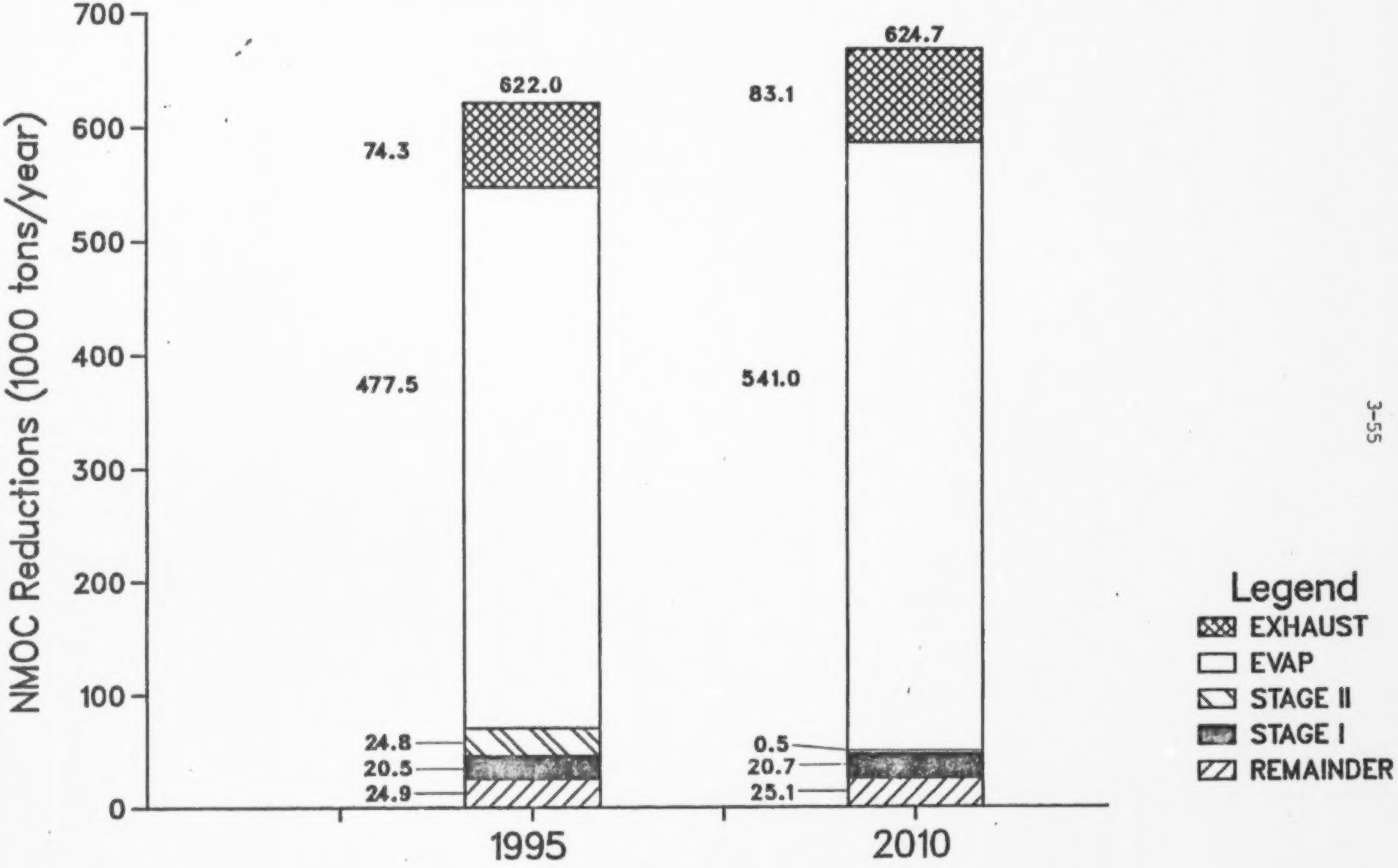
Projected Number of Non-California Urban Ozone Non-Attainment Areas
(Assuming Prior Implementation of Onboard Refueling Control in MY 1990)

Control Scenario	Projection Year 1990	1995	2000	2010
No RVP Control	40	37	40	49
RVP = 11.5	38	35	34	41
11.0	37	33	33	41
10.5	36	32	33	41
10.0	36*	31	32	41
9.5	36	30	30	41
9.0	36	29	30	39
8.5	36	29	30	39
8.0	36	29	30	39

---

* Certification fuel changes in 1990. In-use RVP control to less than 10.5 psi is delayed until 1992 (see Chapter 5).

FIGURE 3-1
NMOC Reductions in 61 Non-California Urban Non-Attainment Areas - RVP Control to 9.0 psi



used for cities located in Arizona, Colorado, Nevada, New Mexico, and Utah; and St. Louis data are used for all other areas.[15] (The design values for the 61 urban areas in this analysis are shown in Table 3-19, and the NMOC:NOx ratios are shown in Table 3-18. For more details on EKMA, see References [16] and [17].)

Using EKMA and the NMOC emissions inventory presented in Table 3-16, projections of future ozone conditions in the 61 non-California urban ozone non-attainment areas were made. The results of this modeling are discussed below.

Tables 3-26 through 3-28 present summaries of the EKMA-based predictions of future ambient ozone conditions in the 61 non-California urban ozone non-attainment areas under various levels of RVP control, assuming prior implementation of onboard refueling control in the 1990 model year. (Tables 3-29 through 3-31 present the same information, except that no control of refueling emissions is assumed. The following discussion is based on Tables 3-26 through 3-28 and the assumption of onboard control of refueling emissions.)

Table 3-26 shows the average percent change in ambient ozone concentration with respect to the base level in 1983. The reductions expected to occur under the "No Control" scenario are, of course, in response to programs other than gasoline volatility control. Programs already in place that are projected to result in reductions in ozone precursor emissions, and thus improvements in ozone air quality, include the current Federal Motor Vehicle Control Program (FMVCP) and some controls on stationary sources (see section I.B.4 of this chapter). The current FMVCP accounts for most of the reductions that are projected in the "No RVP Control" case.

However, the additional ozone reductions shown under the eight RVP control scenarios in Table 3-26 are due solely to NMOC reductions attained through the control of in-use and certification fuel RVP. For example, if in-use RVP was controlled to 10.0 psi in 1992 (10.5 psi in 1988), and certification RVP was raised to 10.0 psi in 1990, ambient ozone concentrations by the year 1995 would be expected to decrease an additional 3 percent beyond the baseline RVP scenario (i.e., 11 percent instead of 8 percent lower than 1983 levels).

Estimates of the total annual exceedances of the ozone NAAQS are presented in Table 3-27 for each of the RVP control scenarios. The NAAQS for ozone calls for an effective limit of 0.125 ppm on the fourth highest daily maximum one-hour ozone concentration in any three-year period; the numbers of exceedances listed in the table represent the total number of days this maximum hourly ozone concentration is expected to

Table 3-26

Average Percent Change* in Ambient Ozone Concentrations in 61 Non-California Urban Non-Attainment Areas
(Assuming Prior Implementation of Onboard Refueling Control in MY 1990)

Control Scenario	Projection Year 1990	1995	2000	2010
No RVP Control	-7	-8	-8	-4
RVP = 11.5	-7	-10	-9	-6
11.0	-8	-10	-10	-6
10.5	-9	-11	-10	-7
10.0	-9**	-11	-10	-7
9.5	-9	-11	-10	-7
9.0	-9	-11	-11	-7
8.5	-9	-12	-11	-7
8.0	-9	-12	-11	-7

---

* Relative to the base-year (1983) levels.

** Certification fuel changes in 1990. In-use RVP control to less than 10.5 psi is delayed until 1992 (see Chapter 5).

Table 3-27

Total Number of Exceedances of the Ozone NAAQS in 61 Non-California Urban Non-Attainment Areas

(Assuming Prior Implementation of
Onboard Refueling Control in MY 1990)

Control Scenario	Projection Year			
	1990	1995	2000	2010
No RVP Control	246	237	241	283
RVP = 11.5	244	228	225	261
11.0	236	219	220	261
10.5	232	212	216	258
10.0	232*	206	214	256
9.5	232	203	208	256
9.0	232	200	208	256
8.5	232	198	206	253
8.0	232	198	205	252

---

* Certification fuel changes in 1990. In-use RVP control to less than 10.5 psi is delayed until 1992 (see Chapter 5).

Table 3-29

Average Percent Change* in Ambient Ozone Concentrations in 61 Non-California Urban Non-Attainment Areas

(Assuming No Control of Refueling Emissions)

Control Scenario	Projection Year 1990	1995	2000	2010
No RVP Control	-7	-8	-7	-3
RVP = 11.5	-7	-9	-9	-6
11.0	-8	-10	-9	-6
10.5	-9	-10	-9	-6
10.0	-9**	-11	-10	-6
9.5	-9	-11	-10	-6
9.0	-9	-11	-10	-6
8.5	-9	-11	-10	-6
8.0	-9	-11	-10	-6

---

* Relative to the base-year (1983) levels.

** Certification fuel changes in 1990. In-use RVP control to less than 10.5 psi is delayed until 1992 (see Chapter 5).

Table 3-30

Total Number of Exceedances of the Ozone NAAQS in 61 Non-California Urban Non-Attainment Areas (Assuming No Control of Refueling Emissions)

Control Scenario	Projection Year			
	1990	1995	2000	2010
No RVP Control	246	239	250	292
RVP = 11.5	244	232	233	265
11.0	236	226	230	264
10.5	232	220	225	262
10.0	232*	213	222	262
9.5	232	208	219	261
9.0	232	203	218	261
8.5	232	203	213	260
8.0	232	201	210	258

---

* Certification fuel changes in 1990. In-use RVP control to less than 10.5 psi is delayed until 1992 (see Chapter 5).

Table 3-31

Projected Number of Non-California Urban Ozone Non-Attainment Areas (Assuming No Control of Refueling Emissions)

Control Scenario	Projection Year 1990	1995	2000	2010
No RVP Control	40	38	41	51
RVP = 11.5	38	35	35	43
11.0	37	35	34	43
10.5	36	33	34	41
10.0	36*	33	34	41
9.5	36	31	33	41
9.0	36	30	33	41
8.5	36	30	32	41
8.0	36	30	31	41

---

* Certification fuel changes in 1990. In-use RVP control to less than 10.5 psi is delayed until 1992 (see Chapter 5).

exceed 0.125 ppm in the 61 areas modeled. Only the peak monitoring site in each of the 61 areas is considered. Thus, 365 is the maximum possible number of annual exceedances per area. Table 3-27 shows, for example, that control of both in-use and certification fuel RVP to 9.0 psi is estimated to reduce the combined total number of ozone exceedances in the 61 urban areas by approximately 16 percent relative to the baseline RVP scenario in 1995 (i.e., 200 rather than 237 total exceedances).

Finally, Table 3-28 estimates the total number of non-California urban areas expected to be in non-attainment of the ozone NAAQS under the various RVP control options. As shown, RVP control to 9.0 psi is projected to enable about 8 more areas to come into attainment in 1995. One significant limitation associated with evaluating control options on the basis of number of non-attainment areas must be kept in mind: only those areas that fall below the NAAQS as a result of the action are distinguishable. In other words, the value of bringing an area closer to attainment is not recognized unless attainment is actually projected to occur. Therefore, estimated overall emissions reductions or changes in average ambient concentrations as a result of a particular action are more indicative of the environmental impact of that action than is the projected number of non-attainment areas.

IV. Benzene Emissions and Incidence Analysis

The control of in-use fuel volatility is likely to result in changes to the composition of gasoline, which in turn will result in changes in the composition of hydrocarbon emissions from motor vehicles. This section uses the benzene mass emission fractions (mass of benzene as a fraction of the total mass of hydrocarbons) developed in section III of Chapter 2 to estimate the impact of fuel volatility control on mobile source benzene emissions. This is followed by a discussion of the impact of these changes in benzene emissions on the cancer incidences resulting from mobile source benzene exposure.

A. Benzene Emissions

In section III of Chapter 2, benzene mass fractions associated with each level of RVP control were developed. Separate fractions were derived for exhaust, evaporative, and refueling hydrocarbon emissions. At each RVP level, distinct exhaust benzene emission fractions are presented for three vehicle categories based on catalyst technology: vehicles equipped with 3-way catalysts; vehicles equipped with 3-way-plus-oxidation catalysts; and pre-1980 vehicles, and those post-1980 vehicles equipped only with oxidation catalysts. Similarly, distinct evaporative benzene emission fractions were provided for carbureted and fuel-injected vehicles. A single refueling benzene emission fraction was given for each RVP level. These fractions were summarized in Table 2-63.

Relevant data from MOBILE3 (e.g., registration and catalyst technology distributions) were used to weight the exhaust and evaporative benzene emission fractions by the fraction of vehicle miles travelled (VMT) for each technology category. The resulting fleet VMT-weighted benzene emission fractions were then multiplied by the emission factors generated in section I.A. of this chapter to produce exhaust benzene and evaporative benzene emission factors in milligrams per mile (mg/mi). These are presented in Table 3-32, with evaporative benzene emissions shown as a range because of uncertainties in the relationship between fuel benzene content and evaporative benzene emissions. Only the emission factors corresponding to 11.5, 10.5, 9.5, and 9.0 psi RVP are included in the table.*

The procedure for estimating the refueling benzene emission factors shown in Table 3-32 begins with the refueling benzene fractions shown in Table 2-63 (g Bz/gal fuel dispensed). These were divided by the corresponding total refueling emission factors (g HC/gal fuel dispensed), interpolated from those presented in Table 2-45, to yield benzene mass fractions (g Bz/g HC) for refueling emissions. Multiplying these mass fractions (which are the same for all vehicles) by the appropriate refueling emission factors (g/mi), determined as part of the analysis in section II of this chapter, yields the refueling benzene emission factors shown in Table 3-32.

Finally, the exhaust, evaporative, and refueling emission factors for each vehicle category are summed to give the total benzene emission factors presented in the bottom section of Table 3-32. The evaporative benzene ranges are incorporated in these totals. The relatively large ranges in these factors, relative to the incremental change as a function of RVP level, are reflective of some of the uncertainties inherent in these estimates.[18]

These benzene emission factors, when multiplied by the nationwide VMT for each category, yield the estimated mobile source benzene emissions shown in Table 3-33.[10] The ranges in these estimates again reflect the ranges in the evaporative

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* RVPs of 8.0 and 8.5 psi were not evaluated since the available Bonner and Moore refinery modeling, from which the fuel benzene content was estimated, did not evaluate RVPs below 9.0 psi. Simple extrapolation was not deemed appropriate due to the complex refinery operations involved, some of which increase fuel aromatic content and some of which do not. Also, the effect of RVP control was so small that presenting results for 10.0 and 11.0 psi serves no useful purpose.

Table 3-32

Benzene Emission Factors* (mg/mi)
(Assuming Prior Implementation of
Onboard Refueling Controls in MY 1990)

Light-Duty Vehicles

RVP	1990**			1995			2000		
(psi)	Exht	Evap	Refu	Exht	Evap	Refu	Exht	Evap	Refu
11.5	44	12-15	2	33	7-8	1	31	5-6	<1
10.5	43	13-14	2	30	7-8	1	27	5-6	<1
9.5	43	11-15	2	30	6-8	1	27	5-6	<1
9.0	42	11-16	2	30	6-9	1	28	5-6	<1

Light-Duty Trucks

RVP	1990			1995			2000		
(psi)	Exht	Evap	Refu	Exht	Evap	Refu	Exht	Evap	Refu
11.5	135	23-28	3	98	14-17	2	74	10-11	<1
10.5	133	26-27	3	93	15-16	2	66	10-11	<1
9.5	133	22-31	3	92	14-18	2	66	10-12	<1
9.0	132	23-31	3	92	14-19	2	66	10-12	<1

Heavy-Duty Vehicles

RVP	1990			1995			2000		
(psi)	Exht	Evap	Refu	Exht	Evap	Refu	Exht	Evap	Refu
11.5	130	53-68	4	101	40-50	3	91	36-45	1
10.5	130	63-67	4	99	41-44	3	88	35-37	1
9.5	132	55-77	4	101	38-52	3	90	33-45	1
9.0	133	58-79	4	101	41-55	3	90	36-48	1

Total Benzene Emission Factors

RVP	1990			1995			2000		
(psi)	LDV	LDT	HDV	LDV	LDT	HDV	LDV	LDT	HDV
11.5	58-61	161-166	187-202	41-42	114-117	144-154	36-37	84-85	128-137
10.5	58-59	162-163	197-201	38-39	110-111	143-146	32-33	76-77	124-126
9.5	56-60	158-167	191-213	37-39	108-112	142-156	32-33	76-78	124-136
9.0	55-60	158-166	195-216	37-40	108-113	145-159	33-34	76-78	127-139

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* Exhaust and evaporative emission factors from in-house MOBILE3 (Run 028, March 3, 1986).

** Calendar year

Table 3-33

Projected Mobile Source Benzene Emissions (Assuming Prior Implementation of Onboard Refueling Controls in MY 1990)

RVP (psi)	Benzene Emissions* (x 1000T) 1990	1995	2000
11.5	149-155	108-111	91-93
10.5	150-152	102-104	82-84
9.5	150-152**	100-105	82-85
9.0	150-152**	100-107	83-86

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* From gasoline-fueled mobile sources only.

** In-use RVP control to less than 10.5 psi is delayed until 1992 (see Chapter 5).

benzene emission fractions discussed above. These estimated emissions do not include benzene emissions from diesel vehicles, which are very low relative to those from gasoline-fueled vehicles and will not be affected by RVP control.[19]

Although the projected emissions in Table 3-33 show a slight tendency to be lower as RVP is reduced, the reduction is never greater than 10 percent, and is on the order of the ranges in the estimates. Although the benzene emission fractions increase slightly with decreasing RVP, the decrease in the total hydrocarbon emissions slightly overcompensates for this effect. This effect is also small in comparison to the decrease in benzene emissions over time at all RVP levels. These estimates illustrate that mobile source benzene emissions will drop by more than 50 percent from 1982 levels of about 250,000 Mg/yr,[18] regardless of the RVP level assumed.

While exhaust benzene emissions dominate both the nationwide and mobile source inventories, it is important to note that as fleet turnover occurs and exhaust hydrocarbon emissions decrease, the size of the exhaust benzene emission inventory is expected to drop by about 50 percent between 1985 and 2000 even without further vehicle or RVP controls. The same is true for evaporative benzene emissions. Assuming the prior implementation of onboard refueling emission controls, benzene emissions from refueling would be expected to decrease by about 12 percent in 1990, and by about 80 percent by 2000.

B. Incidence Analysis

Benzene is a known human carcinogen at low exposure levels, and has been categorized as a hazardous air pollutant by EPA under Section 112 of the Clean Air Act. This analysis estimates the number of cancer incidences which may occur due to exposure to mobile source benzene emissions and the effect of RVP control on the number of such incidences.

In general, there are two types of exposures involved with mobile source incidences. The first is exposure of the general public to ambient benzene concentrations (ambient exposures), and the second is exposure of individuals to more highly localized concentrations of benzene, such as during refueling operations (individual exposures). Exhaust, evaporative and refueling emissions from mobile sources all contribute to ambient concentrations of benzene and thus to ambient exposures. However, in addition to their contribution to ambient exposures, refueling emissions also pose an additional individual exposure risk. The Gasoline Marketing Study presented an estimate of incidences due to both individual and ambient exposures to refueling benzene emissions, so refueling-related incidences were not recalculated for this analysis.[19] These refueling incidences are presented along with the incidences due to exposures to ambient benzene concentrations arising from exhaust and evaporative emissions.

This analysis was conducted for a base case and four likely RVP control cases, for exhaust and evaporative emissions only.* In-use RVP control was assumed effective in 1988, and vehicle controls were assumed effective for the 1990 model year. Base case incidences from community exposure to benzene refueling emissions were taken from the analysis supporting the gasoline marketing analysis, as noted above, while refueling-related incidences for the RVP control cases were estimated using the benzene fractions of Table 2-63 and the changes in total refueling hydrocarbon emissions from section I of this chapter.

Several steps are necessary to estimate the number of incidences which may result from exposure to exhaust and evaporative benzene emissions. First, the exhaust and evaporative mass fractions were fleet-weighted for each model year, and the results were used with the MOBILE3 HC input data to calculate benzene composite emission factors for calendar years 1985, 1988, 1990, 1995 and 2000. These factors were shown in Table 3-32. The resulting MOBILE3 composite emission factors were then used as inputs to the NAAQS Exposure Model (NEM) to estimate total annual person hours of exposure at different ambient benzene concentrations.[20] The exposure estimates from NEM were then multiplied by the benzene unit risk factor to calculate incidences.

Using the methodology described above, the expected number of cancer incidences was calculated for the base case and four RVP control cases. The results are shown in Tables 3-34 and 3-35 and are discussed below.

First, it is apparent from the base-case results that exhaust and evaporative-related benzene incidences decrease by roughly 55 percent between 1985 and 2000 with or without vehicle or RVP control. This decrease is largely due to the overall reduction in total hydrocarbon emissions as fleet turnover occurs, as illustrated by Tables 3-21 through 3-25. Also for the base case, it is worth noting that exhaust-related incidences outnumber evaporative-related incidences by about 4:1, and that refueling-related incidences are considerably less than those related to evaporative emissions.

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* Base case: in-use RVP = 11.5 psi, certification fuel RVP = 9.0 psi; control cases: in-use RVP = certification fuel RVP = 11.5, 10.5, 9.5, and 9.0 psi RVP.

Table 3-34

Incidences Due to Mobile Source Benzene Exposure

Year	Evaporative*	Exhaust	Sub Total	Refueling**	Grand Total
Base Case***					
1985	16-20	62	78-82	7	85-89
1988	11-14	49	60-63	7	67-70
1990	10-12	42	52-54	6	58-60
1995	6-8	32	38-40	3	41-43
2000	5-6	30	35-36	1	36-37
RVP = 11.5 psi					
1988	11-14	49	60-63		
1990	10-12	42	52-54		
1995	7-8	30	37-38		
2000	4-5	29	33-34		
RVP = 10.5 psi					
1988	13-15	47	60-62		
1990	10-11	41	51-52		
1995	6-7	30	36-37		
2000	5-6	28	33-34		
RVP = 9.5 psi					
1988	11-16	48	59-64		
1990	9-12	41	50-53		
1995	6-7	31	37-38		
2000	5-6	28	33-34		
RVP = 9.0 psi					
1988	12-16	48	60-64		
1990	9-12	41	50-53		
1995	6-8	31	37-39		
2000	5-7	28	33-35		

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* Low and high range estimates.

** Refueling incidences were taken directly from analysis supporting the Gasoline Marketing Study, with the 1990 and later values adjusted for the impact of onboard controls.

*** In-use RVP = 11.5 psi, certification RVP = 9.0 psi.

Table 3-35

Differences in Number of Incidences: Control Cases vs Base Case

Year/ Category		RVP Control Level**			
		11.5 psi	10.5 psi	9.5 psi	9.0 psi
Low Evaporative Emission Range**					
1988:	Evaporative	0	+2	0	+1
	Exhaust	0	-2	-1	-1
	Total	0	-1	-2	-2
1990:	Evaporative	0	0	-1	-1
	Exhaust	0	-1	-1	-1
	Total	0	-1	-3	-3
1995:	Evaporative	+1	0	0	0
	Exhaust	-2	-2	-1	-1
	Total	-1	-2	-1	-2
2000:	Evaporative	-1	0	0	0
	Exhaust	-1	-2	-2	-2
	Total	-2	-2	-2	-2
High Evaporative Emission Range**					
1988:	Evaporative	0	+1	+2	+2
	Exhaust	0	-2	-1	-1
	Total	0	-2	0	-1
1990:	Evaporative	0	-1	0	0
	Exhaust	0	-1	-1	-1
	Total	0	-2	-2	-2
1995:	Evaporative	0	-1	-1	0
	Exhaust	-2	-2	-1	-1
	Total	-2	-3	-2	-2
2000:	Evaporative	-1	0	0	+1
	Exhaust	-1	-2	-2	-2
	Total	-2	-2	-2	-1

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* Certification fuel RVP = in-use fuel RVP.

** Evaporative emission range depends on benzene emissions model used (see section III of Chapter 2).

Second, the vehicle-control approach to reducing total in-use hydrocarbon emissions (in-use fuel RVP = certification fuel RVP = 11.5 psi) shows only a slight reduction in the number of incidences (one or two) in 1995 and 2000. Vehicle control is dependent on fleet turnover to reduce in-use emissions, so no differences are noted in 1990, the year such controls are assumed to begin. Since the benzene mass fractions (exhaust and evaporative) are the same for the base case and the vehicle-control case, any reduction of in-use benzene emissions and related incidences arises as a result of the reduction in total hydrocarbon emissions which would accompany vehicle controls. As the results in Table 3-35 indicate, the overall impact of vehicle controls would be small.

The third area for discussion is the effect of in-use RVP control on the estimated number of incidences. As can be seen in Tables 3-34 and 3-35, in-use RVP control has little or no impact on the number of incidences. However, when there is a small effect, it is nearly always a reduction in incidences. The explanation is that decreases in benzene emissions due to decreases in hydrocarbon emissions are largely offset by the increases in the benzene mass fraction (shown in Table 2-63). As explained earlier, RVP control is likely to lead to increases in the benzene and total aromatic content of gasoline, which in turn increases the benzene mass fraction in exhaust and evaporative emissions.

If gasoline composition with respect to benzene and total aromatic content remained at current levels under RVP control, a greater decrease in the number of incidences would likely be noted. Given the accuracy of the modeling techniques used here, however, it is most reasonable to say that RVP control will have no little or impact on exhaust- or evaporative-related incidences.

In summary, the analysis shows that approximately 80 incidences occur currently due to exhaust and evaporative benzene emissions and that this number will drop by more than 50 percent to about 35 in the year 2000 as fleet turnover occurs and total hydrocarbon emissions decrease. Vehicle control or RVP control would have essentially no effect on the number of incidences or the relative contribution of the emissions (exhaust vs. evaporative) leading to the incidences. More information on how this analysis was performed and some of the areas of uncertainty may be found in an EPA technical memorandum.[18]

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Appendix 3-A

Butane Reactivity

Ozone formation in the troposphere is a complex process involving many reactions and compounds. Hydrocarbons are one group of these compounds which lead to the formation of ozone. However, each hydrocarbon species (i.e., methane, butane, benzene, etc.) reacts at varying rates defined here as the reactivity, resulting in different amounts of ozone formation under the same atmospheric conditions. Reactivity has also been categorized by the rate of hydrocarbon depletion and the rate of nitrogen oxide oxidation, as well as by other criteria, but these are not the focus here. The purpose of this appendix is to present the ozone-related reactivity of butane in relation to other hydrocarbons. Butane is the focus of the appendix since volatility control results in emission reductions which consist primarily of butane.

The majority of evidence in existence supports a high reactivity of butane with respect to ozone formation. Historically, the first evidence was obtained in indoor smog chamber testing.[1] Butane was mixed with NOx at ppm-concentrations and irradiated with artificial sunlight. Ozone was produced at concentrations exceeding the air quality standards of 0.12 ppm. Isolated studies have given conflicting results (i.e., ozone yields less than 0.12 ppm) but such conflicts can be explained by differences in butane-to-NOx ratio and other conditions used in the studies.[2,3] The early indoor smog chamber results have been discredited because real atmosphere conditions were not simulated in the indoor smog chambers and because in the real atmosphere, butane reacts in the presence of other hydrocarbons, also. However, butane was found again to be a significant producer of ozone in more realistic outdoor smog chamber studies in which butane was tested mixed with other organics.[4]

In an attempt to rate the reactivity of different chemicals, researchers have developed several reactivity classifications based on different properties as previously mentioned. The classifications used by EPA are based on both reactivity (rated on smog chamber data) and volatility properties and were developed in 1984. The overall reactivity of the chemicals is designated by one of three classes categorized I, II or III corresponding to "unreactive", "borderline", or "reactive", respectively.[5] It is believed within EPA that the "borderline" classification occurs at a reactivity level roughly equal to that of ethane.[6] Table

3-A-1 presents the classification of several organic compounds. Butane is definitely in the "reactive" category based on this scale.

A second reactivity scale developed in the mid-1960s, called the GM scale, is based on the rate of formation of NO_2 (equal in magnitude but opposite in direction of the rate of NO disappearance) under fixed test conditions.[7] (The alkyl-peroxy radical, RO_2, formed from the reaction of hydrocarbons in the atmosphere, competes with ozone to react with NO to form NO_2. The alkyl-peroxy radical reacts faster than ozone, thus resulting in an accumulation of ozone.) The GM scale is a relative scale with the specific reactivity of 2,3-dimethyl-2-butane, a highly reactive compound, equal to 100. The reactivities of several hydrocarbons are shown is Table 3-A-2. Butane is also classified as a reactive compound under the GM scale, though in the lowest category of reactive compounds.

A third reactivity scale, developed by the U.S. Department of Health, Education, and Welfare (HEW) in the mid-1960s, is based on six criteria: equilibrium oxidant, peroxyacetyl nitrate (PAN), formaldehyde, and aerosol formation, eye irritation and plant damage.[8] The hydrocarbons were rated for each of the six categories (0 = no effect and 10 = maximum effect). The average of the six ratings is the relative reactivity. The averaged response for various hydrocarbons are presented in Table 3-A-3. On the HEW scale butane is rated as non-reactive along with other paraffins up through the pentanes.

Besides the reactivity scales, other experimental and modeling work has been done to show the effects of butane on ozone. Modeling has shown butane to be from 14 percent to 34 percent as reactive as propene, a highly reactive chemical.[9,10] Based on existing smog chamber and fuel data, one report estimated that nine percent of the ozone generated results from reactions involving butane.[10]

In summary, it appears butane is not one of the most reactive compounds. However, the issue is whether or not butane reacts fast enough to affect ozone in the breathing zone. Both the EPA and GM reactivity scales rate butane as a reactive compound. (The older HEW scale is based on a number of criteria, not all of which pertain to ozone.) Modelling and smog chamber data also verify the contribution of butane to ozone formation in the troposphere. Based on available information, it is EPA's position that butane is a photochemically reactive compound which contributes to ground level ozone formation. Therefore, reductions in butane emissions through in-use fuel volatility control are expected to lead to subsequent reductions in ambient ozone levels.

Table 3-A-1

EPA Classification of Hydrocarbon Reactivity

I	II	III
Ethane	Benzene	Propane
Acetylene		i-Butane
		n-Butane
		Xylenes
		Formaldehyde
		Methanol
		Cyclohexane
		Ethylene
		Propene

Table 3-A-2

GM Scale of Hydrocarbon Reactivity Classes and Class Specific Reactivity

Class	Specific reactivity	Hydrocarbons
I	0	methane ethane propane acetylenes benzene
II	2	mono alkyl benzenes C_4 and higher molecular weight paraffins ortho and para dialkyl benzenes cyclic paraffins
III	5	ethylene meta dialkyl benzenes formaldehyde and higher aldehydes
IV	10	1-olefins (other than ethylene) diolefins tri and tetra alkyl benzenes internally bonded olefins
V	30	internally bonded olefins
VI	100	internally bonded olefins with substitution at the double bond cyclo olefins

Table 3-A-3

HEW Scale of Hydrocarbon Reactivity

Substance or Sub-Class	Averaged Response
C_1-C_5 paraffins	0
acetylene	0
benzene	0
C_6 paraffins	1
toluene (and other monoalkylbenzenes)	3
ethylene	4
diolefins	6
dialkyl and trialkylbenzenes	6
internally double-	
1-alkenes	7
bonded olefins	8

Appendix 3-A References

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CHAPTER 4

Vehicle Controls

This chapter will focus upon the modifications to current evaporative emissions control systems (ECSs) needed in order to improve their ability to control evaporative emissions. The need for such improvement stems from the proposed changes in the certification test procedure to underscore EPA's intent to have manufacturers design the evaporative control systems to operate effectively in-use. These changes are: 1) eliminate the discrepancy between certification and in-use fuel volatility, and 2) begin the test with a canister loaded to breakthrough. The discussion is broken up into three sections: the technological feasibility of the potential modifications - Section I; the costs associated with such modifications - Section II; and the overall conclusions - Section III.

I. Technology

As has been indicated in Chapter 2, vehicular evaporative control systems may require modification in order to meet the requirements imposed by the potential changes in the certification test procedure. As will be shown, there is a strong interrelation between the canister size and design, and purge. Depending on the actual situation, it is no longer considered necessary to fully increase both canister size and purge rate. Although some of these potential design options will be mentioned, this section will take a worse case approach in the canister/purge discussion. This worse case approach will assume a minimal research and development (R&D) effort by the automobile industry. Therefore, the change in capacity of the canister required to adsorb and desorb hydrocarbon vapors will be discussed separately from the changes required for the control system to purge the evaporative canister.

A. Canister Modifications

The following section describes the adsorption and desorption characteristics of an activated carbon canister. The succeeding section describes the necessary working capacity required to capture the increased evaporative emissions from a higher RVP fuel.

1. Canister Characteristics

The carbon canister adsorbs the gasoline vapors that would otherwise escape into the atmosphere during hot soaks and diurnals. Under predetermined operating conditions, the engine burns these vapors by pulling air through the canister and into the engine. The amount of gasoline vapors that the canister can cyclically adsorb (adsorb/desorb) is called the working capacity. This capacity is dependent upon internal and external factors to the evaporative control system. The internal factors are: 1) charcoal type and particle size*, 2) the volume of charcoal in the canister, and 3) the configuration of the canister. The external factors are: 1) the ambient temperature and humidity, 2) the volume of purge air drawn through by the control system, 3) the purge temperature, and 4) the composition of fuel vapors being adsorbed. These factors will now be discussed further.

Vapor adsorption and desorption is a purely physical process, with Van der Wall's bonding acting as the force holding the vapor to the charcoal.[1] The effectiveness of this bonding will depend upon the average particle size, the ratio of surface area to volume of the individual particles, and the size of the pores in which the vapor molecules are adsorbed. These various elements determine what is defined as the charcoal "working capacity" (measured as grams HC per 100 cubic centimeters (cc) of charcoal).

In a given volume of charcoal, smaller particles can be compacted more tightly, thus increasing the likelihood that the vapors will come in contact with the surface of the particles. The tighter compaction of particles also allows for a greater mass of charcoal in a given volume, resulting in increased volumetric working capacity. This increase in charcoal working capacity has been seen in a designed experiment.[2] This same compaction, however, decreases permeability and reduces the flow rate through the canister at a specific pressure drop. It is for this reason that, in current practice, the maximum pressure drop across the canister at a specified flow rate is usually the determining factor in the selection of particle size.[3]

A greater surface area for a given particle implies more sites to which vapor molecules can be bonded. Therefore a particle with a highly convoluted surface having a large surface area to volume ratio will necessarily be a better adsorber than a particle of similar size with a smaller surface area to volume ratio. Increasing this ratio by disturbing the surface of a particle is the process that is referred to when carbon is defined as being activated.[4]

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* Particle size of a given charcoal type is usually expressed in terms of mesh size and is expressed in the form A x B. A and B are divisions per inch and A x B size particles are able to pass through (1/A) inch by (1/B) inch openings. Thus, larger values of A and B represent a smaller mesh size and therefore smaller particles.

Finally, pore size can affect the charcoal working capacity, although the effect is not as clear as with particle size or the surface area-to-volume ratio. In general, vapor molecules will adsorb into pores of a size comparable to their own. It is possible, however, that larger particles can become lodged in pores in such a manner as to block access to more pore space that smaller particles could occupy. Since these larger particles are heavier and the bonding forces are stronger, they may not be removed during the purge cycle, and a portion of the carbon's adsorptivity will be lost.[1]

A charcoal's working capacity is measured as its ability to adsorb and desorb HC vapor, on a volumetric basis, under a relatively standardized test procedure. Working capacity is usually measured as grams of butane per 100 cc of charcoal, as butane is easy to work with, yields consistent results and is the dominant compound in vehicular evaporative emissions.

Typical levels of "butane working capacity" for various charcoals are presented in Table 4-1. These values will not necessarily translate directly into charcoal working capacities for vehicular evaporative emissions, as these HC vapor mixtures are more complex than simple butane. Since HC species differ in their physical characteristics, they will be adsorbed preferentially and the degree of preference may depend upon carbon type. Thus, equal butane working capacities will not always result in equal gasoline working capacities.[2,4]

Assuming that the characteristics of the charcoal remain the same, there should be a direct relationship between the volume of charcoal used and the system (total) working capacity. This should be clear from the definition of the charcoal working capacity.

Canister configuration may play a role in determining the system working capacity, although this theory is disputed. In a study by Scott Environmental Technology, the specific working capacity of a canister was increased by 12.3 percent by doubling the length of a cylindrical canister while holding the diameter, and therefore the cross sectional area, constant.[2] The theoretical explanation for this increase in working capacity centers on the concept of a "mass transfer zone" (MTZ). This theory states that when the carbon bed is charged, there will exist a zone which is fully saturated with hydrocarbons and a zone where the saturation decreases from fully saturated to completely devoid of hydrocarbons. This MTZ will only operate at half of its theoretical capacity when breakthrough occurs, and its length will not vary with the

Table 4-1

Charcoal Properties*

Charcoal	Manufacturer	Base	Mesh Size	Surface Area (m^2/g)	Apparent Density (lb/ft^3)	Capacity (g/100 cc)	
						Test I*	Test II**
BPL-3	Calgon	Coal	6 X 14	800-1000	23-24	6.8	8.08
WV-A	Westvaco	Wood	10 X 25	1500-1700	15-18	8.5	8.31
WV-A	Westvaco	Wood	14 X 35	1600-1800	16-19	9.0	8.89
Extruded***	Westvaco	Wood	****	-----	20-21	10.5	--

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* Specified by charcoal manufacturer in "Westvaco's Wood-Base Carbons Improve Evaporative Emission Control," Billy Kornegay, Ph.D., P.E., September 1980.

** From a test performed by Westvaco.

*** Data from phone conversation with Bill Kornegay of Westvaco Corporation on November 5, 1984.

**** Not specified, but equivalent pressure drop of mesh size 6 x 14.

length of the carbon bed. A carbon bed whose length is twice that of the MTZ will have a capacity at breakthrough of 75 percent of maximum.* By doubling the length of the carbon bed, with the length of the MTZ remaining constant, there will be less under-utilization of capacity, and the capacity at breakthrough will be 87.5 percent of maximum.** This theoretical increase of 12.5 percent is quite close to that observed in the testing.[2]

Using a different approach, a 1969 SAE paper by R.S. Joyce et al, indicated that system working capacity is not significantly related to canister configuration.[3] While both approaches acquired data from adsorption/desorption cycles, Joyce defined working capacity as the amount of butane (hydrocarbons) desorbed during a 20 minute of time, rather than the amount adsorbed to the point of breakthrough. It is not known if the same conclusion would have been reached using a different period of time. Also, it is not known how different charcoals affect the capacity/configuration results.

Assuming that canister configuration generally does affect working capacity, future designs could optimize the canister shape. To increase the working capacity and still remain within overall size limitations found in some engine compartments, future designs potentially could incorporate baffles to increase the effective length to diameter ratio.

External factors also affect the system working capacity. For a given canister, the total amount of hydrocarbons desorbed is dependent on the total volume of purge air. Working capacity is also dependent on the desorption and adsorption temperatures. For a common Calgon charcoal, increasing the desorption/adsorption temperature difference from 0 to 75°F increases the carbon working capacity by 48 percent.[5] Therefore, the working capacity can be increased with higher temperature purge air.[2,4] This too could potentially minimize canister size and purge rate. Due to the non-linear nature of HC desorption, the increase in hydrocarbons desorbed by a heated purge possibly could offset the usual decrease with time, creating a more constant purge density and therefore a more manageable purge.

Increased humidity will decrease the working capacity of a charcoal canister. Fortunately this is not a lasting effect as charcoal has a higher affinity for hydrocarbons than for water vapor.[2]

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* Figured as: [0.5 (length) x 1.0 (capacity utilized)] +
[0.5 (length) x 0.5 (capacity utilized)].

** Figured as: [0.75 (length) x 1.0 (capacity utilized)] +
[0.25 (length) x 0.5 (capacity utilized)].

The adsorptivity of charcoal has been found to be dependent upon the vapor composition of the evaporative emissions.[2] This is illustrated in Figure 4-1, showing the average charcoal working capacities for two coal-based charcoals tested on 8.7 and 13.8 RVP (psi) fuels. According to the Scott study, hydrocarbon molecules larger than C_6 are more easily retained in the carbon than the "lighter" hydrocarbons.[3] They felt the larger molecules were firmly lodged in the carbon structure and therefore required a higher energy to release. Since high RVP fuel produces more lighter-end hydrocarbons than low RVP fuel, the working capacity will be higher. The increase in charcoal working capacity with increasing RVP will translate into a higher system working capacity.

2. Required Working Capacity

Changes in fuel volatility may require changes in system working capacity. To ensure that the changes in canister capacity are not underestimated, existing canisters are assumed to have barely sufficient capacity for the emissions from 9.0 RVP fuel. The change in system working capacity necessary to meet the requirements of the potential changes in fuel volatility can therefore be estimated by considering the resulting changes in uncontrolled emissions. These must be adjusted, however, to reflect the changes in working capacity that will occur automatically due to the relation to fuel volatility. The difference will represent the amount of extra control that the Emission Control System (ECS) designer will have to develop.

Figure 4-2 shows how the required amount of extra system working capacity is determined. Curve 1 shows the relationship between uncontrolled evaporative emissions and fuel volatility. The curve has been normalized so that emissions from a 9.0 RVP fuel, typical of current certification fuel, will equal 1.0. Curve 2 is a reproduction of Figure 4-1, showing the relationship between charcoal working capacity and fuel volatility. This curve has also been normalized such that the value for 9.0 RVP fuel equals 1.0. Curve 3 is the ratio of Curves 1 to 2, and indicates the additional system working capacity required for a given increase in RVP. As an example, a change in the certification fuel to 11.5-psi RVP, while generating 81 percent more emissions, will only require the development of a 60 percent increase in system working capacity. The remaining 13 percent required increase will be obtained from the increase in specific charcoal working capacity.

Figure 4-1

CHARCOAL WORKING CAPACITY vs. RVP

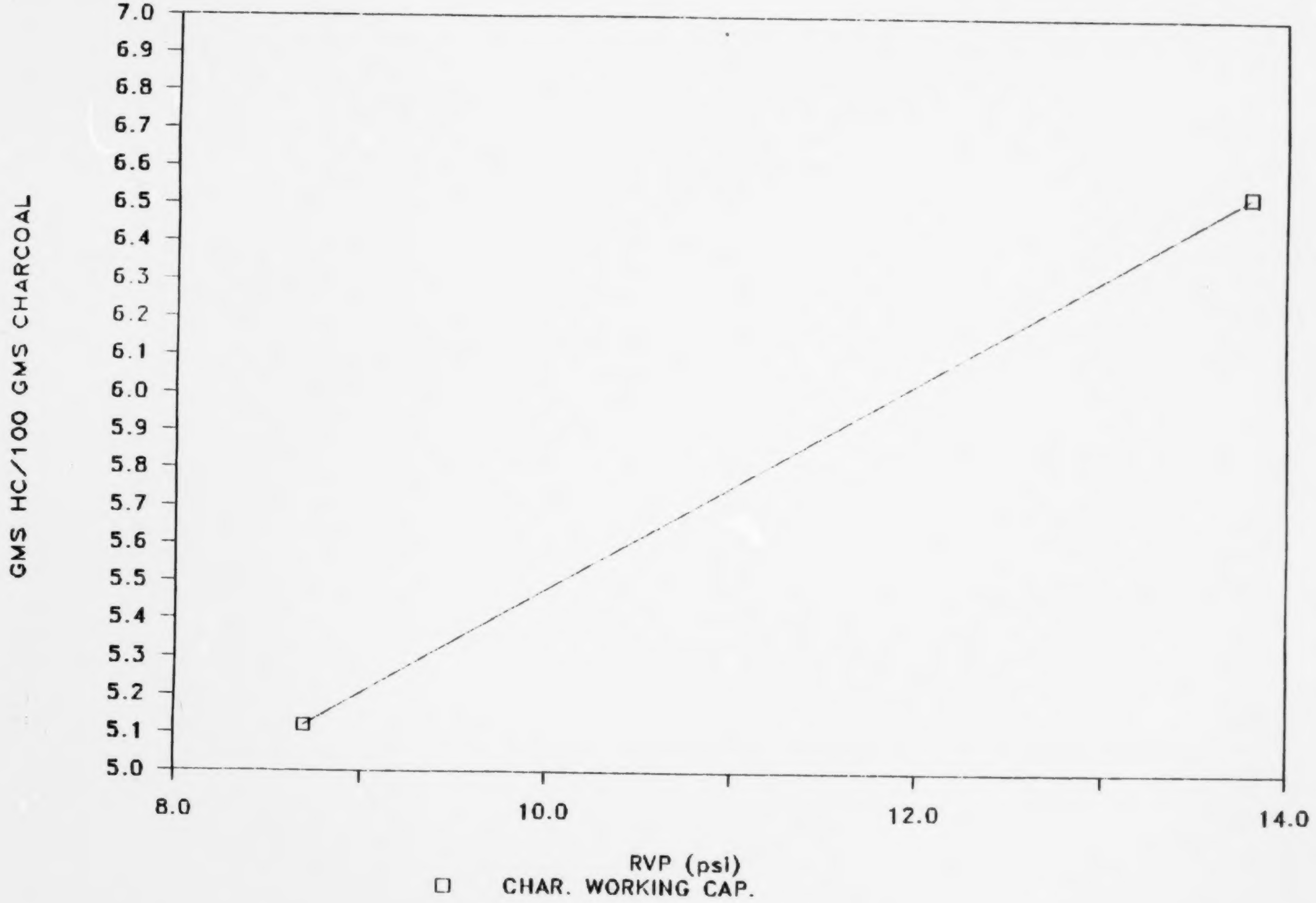
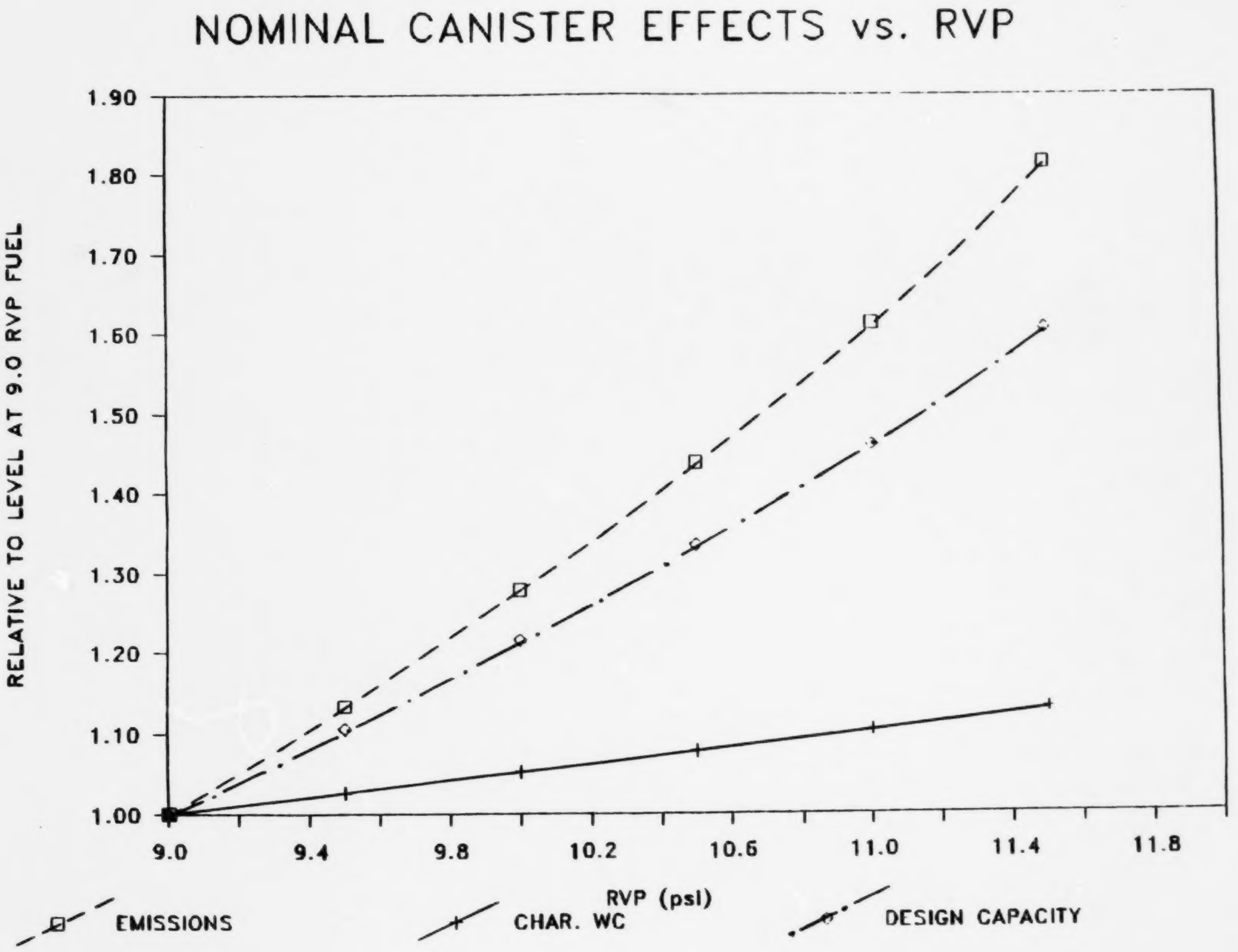


Figure 4-2



NOMINAL CANISTER EFFECTS vs. RVP

Increasing the canister volume is the easiest way to increase system capacity. Changing the canister configuration, increasing the desorption-adsorption temperature differential and changing the specific charcoal working capacity also affect the system capacity.

In 1984, a new type of charcoal was introduced to the market. The properties of this "extruded" charcoal are shown in Table 4-1, along with the properties of other charcoals. Because of the greater working capacity of the extruded charcoal (10.5 vs. 6.8-9.0 g/100 ml), canisters with an equal volume of the extruded charcoal would have a higher working capacity and, thus, be able to support emissions from a higher RVP fuel. This is shown in Table 4-2, taking into account the current carbon type of various manufacturers and curves 1 and 2 of Figure 4-2. By switching to this type of charcoal, then, present systems could support 9.7 - 11.7 RVP fuels without requiring an increase in canister size. An increase in pressure drop with the extruded charcoal may occur. However, the charcoal manufacturer expects to be able to accommodate these concerns by manufacturing various particle sizes.[6]

The option of switching to this extruded charcoal to meet an increase in the RVP certification fuel standard is feasible for some vehicle manufacturers (i.e., those using large particle, coal-based charcoal). However, the remainder of this report will only consider the alternative option of changing canister capacity by changing canister size. This is not meant to imply that charcoals with specific working capacities greater than those traditionally used could not be developed. It is more an indication of a decision not to make any assumptions about their development at this time.

Thus, the likely maximum change in designed canister capacity that may be needed to certify with a new RVP fuel is shown in Table 4-3. For an 11.5 RVP certification fuel, this would be a 60 percent increase in carbon corresponding to: 775 ml for LDVs, 1010 ml for LDTs and 2400 ml for HDVs. To estimate this for LDVs and LDTs, an average industry-wide canister size was determined from 1985 certification records by assuming an equal sales distribution between evaporative families for a given manufacturer and averaging corporate-average canister sizes by projected 1990 sales for each corporation. Only dominant manufacturers were included: General Motors, Ford, Chrysler, Toyota, and Nissan. For HDVs, an average canister size of 4000 ml is used, as it is expected that General Motors will use two canisters totaling 4000 ml of charcoal on all of its HDVs.[7] Details of these calculations are shown in Appendix 4-A.

Table 4-2

Canister Equivalents With Extruded Charcoal

Canister	Present Carbon Type	Mesh Size	Ratio of Increased Working Capacity to Present Working Capacity	Equivalent RVP Control*
Ford	Calgon BPL-3	6 x 14	1.54	11.65
Chrysler	Westvaco WV-A	14 x 35	1.17	9.85
GM	Westvaco WV-A	10 x 25	1.24	10.20
Nissan**	Calgon BPL-3	6 x 14	1.54	11.65

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* From Curve 3 of Figure 4-2.

** Estimated on the basis of charcoal type.

Table 4-3

Average Canister Volume Changes*

	Certification Fuel RVP (psi)													
	8.0		8.5		9.5		10.0		10.5		11.0		11.5	
Vehicle Class	ml	%	ml	%	ml	%	ml	%	ml	%	ml	%	ml	%
LDV	-284	-22	-129	-10	129	10	284	22	439	34	594	46	775	60
LDT	-371	-22	-169	-10	169	10	371	22	574	34	776	46	1013	60
HDV	-880	-22	-400	-10	400	10	880	22	1360	34	1840	46	2400	60

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* Assuming no change in type of charcoal or canister configuration. Based on curves 1 and 3 of Figure 4-2. No change is needed at 9.0 RVP.

It was assumed that all canisters would have to be proportionally increased in size to accommodate an increase in emissions. However, due to the non-linear desorption characteristics of canisters, some manufacturers may decide to oversize their canisters to allow for lower purge rates. At present, many manufacturers use identical canisters on vehicles with differing uncontrolled emissions to reduce manufacturing and inventory costs. Therefore, oversized canisters may have a dual benefit. The relation between canister size and purging will be developed further in the following section.

B. Purge Requirements

Along with a change in vapor storage capacity, a similar change may be required in the ability to desorb these hydrocarbons from the canister. For 11.5 psi RVP fuel, the amount of hydrocarbons purged will have to increase by 81 percent. In addition, a further increase in purging may be required for the proposed change in certification test procedure. This resulting increase in purged HCs must be accomplished without an increase in tailpipe exhaust emissions.

Designing a purge system to handle this increase in canister loading involves the consideration of canister desorption characteristics, along with a number of engine parameters. Due to the non-linearity of canister desorption, the engine may receive a purge stream that varies from an extremely rich mixture to an extremely lean (almost pure air) mixture. If not properly controlled, the initial "slug" of purge may cause rich misfire, or some other driveability problem. However, such improper fuel/air mixtures may also result in exhaust emission "spikes".

Overall, before a vehicle can be designed to handle an increase in purged hydrocarbons, several technical questions must be answered: 1) what is the range of control of existing fuel metering/exhaust treatment (catalyst) systems; 2) what vacuum sources are available; 3) under what conditions can purge occur; and 4) what methods are available to increase the HCs purged? An expansion of each of these questions will now be made.

1. Fuel Metering/Exhaust Treatment Systems

As shown in Chapter 2, an increase in unmetered fuel can increase exhaust emissions. Therefore, the effects of increased purge must be within the range of control of fuel metering systems. An exhaust oxygen sensor can be used to send a rich/lean feedback signal to an onboard computer, which then uses this input to calculate a minor correction for the air/fuel ratio (fuel delivery). Essentially all light-duty gasoline vehicles presently being manufactured use feedback control. With increased concern for fuel economy, and with tighter exhaust standards, feedback systems are expected to become common on light-duty trucks and light heavy-duty vehicles. Heavier heavy-duty vehicles have less stringent exhaust emission standards and therefore will probably not be using feedback systems in the near future, nor will they need to be as concerned with small increases in exhaust emissions. Since they are without catalytic converters, oxygen deficiencies can not cause an increase in tailpipe HC levels, as found in LDVs and LDTs. Also, HDVs have very low fuel economy ratings where unmetered fuel will be only a small fraction of their total fuel consumed. Therefore, the effects of purge will not be as critical with them.

For vehicles with an oxygen sensor, the engine never operates right at stoichiometry, but cycles around it, usually within ±0.5 air/fuel ratios. The range of authority of the oxygen loop is also around ±0.5-1.0, which smooths transitions between operating points, and also minimizes any problems that may occur with sensor degradation or failure. Therefore, either the perturbations in the air/fuel ratio due to the introduction/increase of purge should be well within this range of authority, or a method of satisfactorily expanding this range must be developed.

Due to the transient behavior of typical driving patterns, exhaust emissions and therefore exhaust emission controls have a very transient behavior. The delay time between a signal to change the air/fuel ratio and detection of the resulting change by the oxygen sensor is on the order of 0.1 seconds. In comparison, a single cycle in a 4-stroke engine takes only 0.060 seconds to complete at 2000 rpm (a typical FTP speed). Therefore, an engine may go through several combustion cycles before receiving a correction signal. Due to this finite time for feedback control, a "slow" (1-2 second) introduction/increase of the purge becomes ideal. Presently, a few vehicle models use dampening canisters (small canisters connected between the evap canister and the purge vacuum source) to slowly initiate the purge. Other methods will be suggested later.

2. Available Vacuum Sources

The purge vacuum source must be adequate to purge the canister over an FTP while considering the pressure drop in the evaporative control system. Also, a constant purge to intake air ratio allows increased ingestion of unmetered hydrocarbons during times of increased metered fuel consumption. This proportional purge design maximizes the total purge volume attainable over an LA-4 while staying within the air/fuel perturbation limits.

Existing systems obtain their vacuum from the air cleaner housing, throttle-housing, or intake manifold. The largest vacuum source is located at the intake manifold and is largely dependent on throttle position. Unfortunately, the maximum vacuum occurs during closed throttle position (idle) which is also the period of minimum fuel consumption. Therefore, a method to limit purge (with the associated unmetered fuel) is required. Presently, the common restraining methods use a two-stage purge valve or purge through the PCV valve. The air cleaner and throttle-housing provide a vacuum source proportional to air flow, but the maximum vacuum is much smaller than that available at the intake manifold. Consequently, the intake manifold is the most common vacuum source used for purging. To purge the increased canister loadings associated with higher RVP fuel, the intake manifold will probably continue to be the most common vacuum source. To optimize the purge flow rate through this inversely desired vacuum source, a variable flow purge restraining device would be required.

3. Purge Timing

By starting the certification test procedure with a canister loaded to breakthrough, two conditions must be considered in the purge/canister design. These conditions are as follows.

First, the loaded canister must be adequately purged during the LA-4 prep cycle to allow the vapors from the resulting hot soak and the following diurnal to be fully captured. This condition requires the greatest amount of purge. However, since emissions are not measured during the prep cycle, some emissions effect could occur without penalty.

Second, the canister at a lighter loading must be adequately purged during the ensuing FTP to allow vapors from 10 minutes worth of hot soak between bags 2 and 3, and a full hot soak at the end of the FTP to be captured. In this case, increases in exhaust emissions will have to be generally avoided, due to the stringency of LDV, LDT and lighter HDV HC emission standards.

The LA-4 prep cycle is the most difficult purge condition to meet. The entire cycle lasts only 1370 seconds. Since LDVs and LDTs use feedback control to keep the engine around stoichiometry (the point of highest catalyst efficiency), purging usually occurs only during these closed-loop periods. Therefore, the first 1-3 minutes of the LA-4 typically preclude purging due to the required warm-up time for the catalytic converter and oxygen sensor. In addition, most systems do not allow purging during periods of minimal fuel consumption, i.e. idles and decelerations. This results approximately in 760 seconds (12.7 minutes) available for purging during the LA-4.

The prep cycle condition can be met using one of two strategies. The first strategy is to purge much more than one hot-soak and diurnal loading during the LA-4 prep cycle (where emissions are not measured) by greatly increasing the purge rate and/or canister size. In this way, a lightly loaded canister will be purged during the FTP. The light loading will result in a high air/fuel ratio in the purge line, which will cause minimal perturbation to the engine's scheduled air/fuel ratio.

The second strategy is to increase the purge rate only enough to purge a diurnal and hot soak loading during the LA-4 prep cycle. In this case, the canister will be fully loaded at the beginning of the FTP, and an improved method of purge control will be required to manage the higher density of unmetered hydrocarbons without causing an exhaust effect. Since this strategy is the more difficult of the two, it will be discussed in this section.

4. Methods to Increase Purge

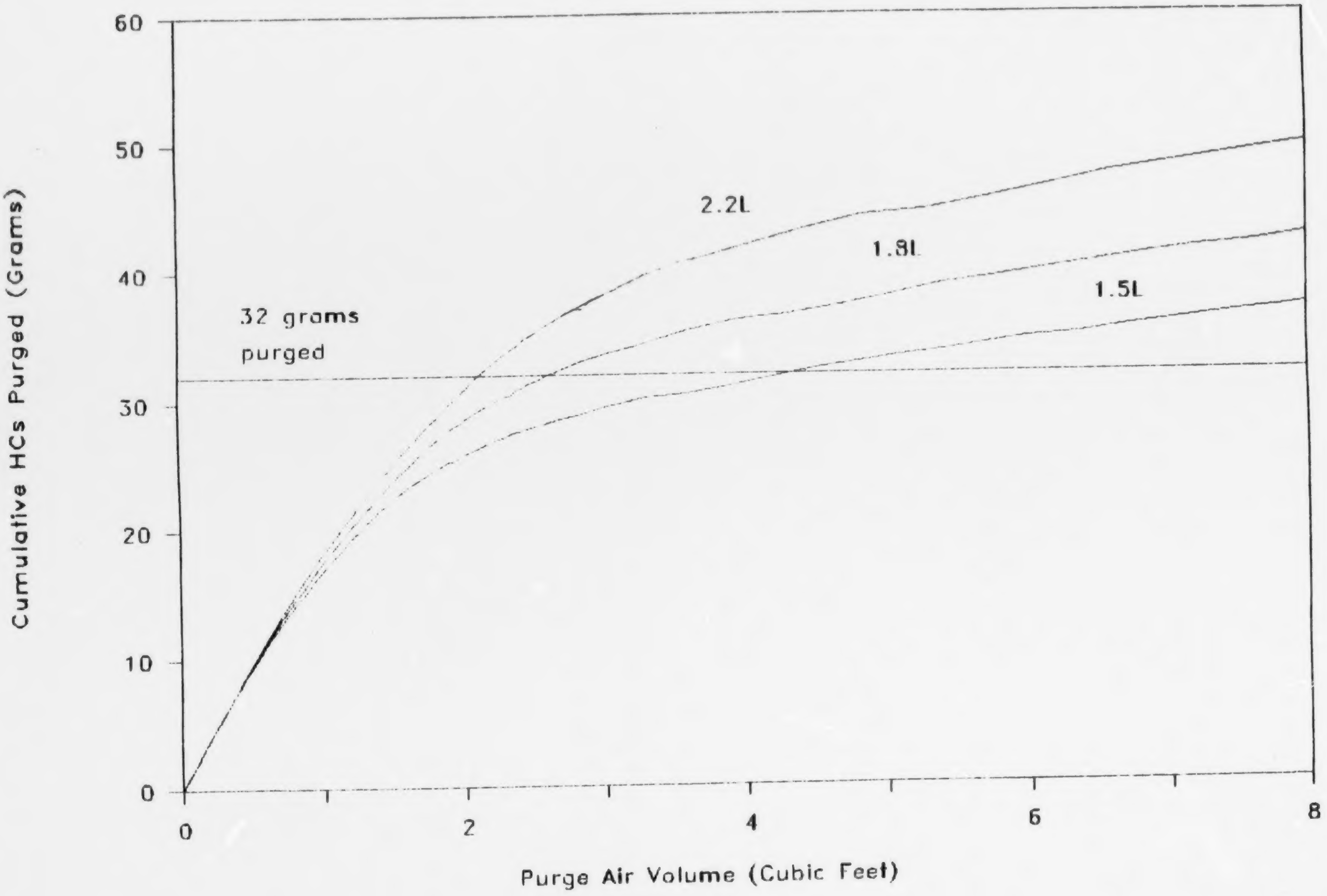
Increasing the amount of hydrocarbons purged can be accomplished by increasing the duration of the purge and/or by increasing the rate of purge. However, due to the limitations previously mentioned, significantly increasing the purge time during an FTP is not viable. The rate of purge, on the other hand, can be increased by increasing the concentration in the purge stream or by increasing the volume of purge air through the canister.

Increasing the purge concentration versus increasing the purge flow rate requires separate design strategies. The purged hydrocarbon concentration is partly dependent on the canister size, load level, and type of charcoal. The canister desorption curves (HC mass purged per total volume of air flow), are always non-linear, initially showing a high rate of desorption and then quickly changing to a slower rate. By increasing the canister size, the canister/purge system can be designed to desorb a hot soak and diurnal using the relatively constant, high desorption rate of the initial portion of the canister curve, along with a low flow rate.

Figure 4-3 graphically shows the effect of increasing the canister size to decrease the total purge air volume required. The calculated hot soak and diurnal loading which must be purged is 32 grams (11.5 RVP fuel). All three canisters are assumed to be loaded to breakthrough at the start of purge,

Figure 4-3

CANISTER PURGE CURVES FOR 3 CANISTERS



which may be close to the "equilibrium point" for the given purge rate and diurnal/hot soak loads. (Actual systems will probably have extra capacity for a factor of safety). As seen by Figure 4-3, by increasing the canister size from 1.5ℓ to 2.2ℓ, the 32 grams can be desorbed with a relatively constant HC purge rate. The resulting "constant" purge concentration eliminates large swings, and therefore eliminates the problem of large "HC slugs" reaching the engine.

Due to the continued high HC concentration at the end of the desired purge, a smaller total volume of purge air can also be used to desorb the 32 grams. As shown in Figure 4-3, the total purge volume decreased from 6.2 ft^3/LA-4 to 1.6 ft^3/LA-4. This smaller volume of purge air also reduces the "vacuum leak" that the primary fuel metering system must be designed to accommodate. Therefore, an oversized canister can help minimize HC density swings in the purge stream, along with reducing the required volume of purge air. Due to low flow rates, deviation in the scheduled air/fuel ratio should be small, even when the canister is empty.

The other method to increase the total amount of hydrocarbons purged requires increasing the total volume of air flow through a "normally sized" canister. This can partly be accomplished by designing a proportional purge system using a variable flow purge valve. In addition, the flow rate schedule may also have to be increased to obtain the total volume of required purge air. Unfortunately, this increase in purge air may complicate the control strategy of the air/fuel ratio. For these situations, two possible solutions are discussed below.

One possible solution to an air/fuel ratio complication is to increase the total range of authority of the oxygen loop. In this way, the purge can be introduced within the normal air/fuel ratio tolerance, and slowly increased as the feedback system adjusts the metered fuel to obtain stoichiometry. To accomplish this type of control, a slow-opening, variable flow purge valve could be used, along with the corresponding modifications in the fuel scheduling algorithm. The valve could be a diaphragm operated control valve in conjunction with a vacuum delay valve, or an electric solenoid valve with frequency modulation.

The diaphragm valve could receive a damped vacuum signal proportional to the air flow (e.g., from the air cleaner), and then limit the purge accordingly. However, with the improved control from electronics, pneumatic systems are being phased out. Some manufacturers are already starting to upgrade their purge control by installing electrical solenoids with frequency modulation. The electric solenoid can be operated by the onboard computer, which allows more flexibility and precision in system control. Since the purge HC concentration decreases with increased purge time, future onboard computer systems could be designed to monitor the purge time from engine start up and then slowly increase the scheduled flow rate as time progressed. According to an SAE seminar on sensors and actuators, plenty of program/memory space is available in onboard computers, so there should be no need to increase the amount of computer hardware for software requirements.[8]

Another possible solution to the air/fuel ratio complication involves a change in fuel control strategy, along with the modulating purge solenoid valve. Since the purge solenoid valve is controlled by the onboard computer, the scheduled air/fuel ratio can be adjusted anytime purging occurs. By going slightly lean with the metered fuel, a larger amount of purged fuel can be introduced to the engine within the air/fuel ratio tolerance. The oxygen sensor can then make the "fine-tune" adjustments to account for the actual variability in unmetered fuel, along with the typical fuel/air fluctuations. The purge algorithm can even be designed with a time variance for the metered fuel adjustment, to account for the decrease in purged hydrocarbons with increasing purge time. The approximate amount of purge air flow can also be incorporated into the lean air/fuel algorithm, so that a purge failure will force the resulting air/fuel ratio towards stoichiometry (via the reduction in net air flow).

Both of the above solutions involve changes in the fuel control strategy, along with a modulating solenoid valve. Due to potential driveability and emission complications in expanding the total range of authority of the oxygen sensor, shifting the scheduled air/fuel ratio during purge may be the preferred method. To learn if this solution is viable, a theoretical calculation is shown below for a "worst-case" vehicle (small fuel consumption with large canister loading), using the modified air/fuel ratio algorithm. The hypothetical carbureted vehicle has a city fuel economy of 40 mpg and a 13 gallon fuel tank resulting in a canister loading of 32 grams (diurnal and hot soak) on 11.5 RVP fuel. By finding the amount of stoichiometric air consumed by the engine during purge, the necessary deviation in the air/fuel ratio required to purge 32 grams can be calculated. The stoichiometric air consumption can be estimated by multiplying the approximate fuel consumed during purge times, by 14.7 (the stoichiometric air/fuel ratio). For this theoretical situation, purging is assumed to occur only during cruise and acceleration modes of the LA-4.

The modal fuel consumption values for this hypothetical vehicle were prorated from a modal test of a 1987 GMC van (city fuel economy of 21.7 mpg). Table 4-4 shows the measured fuel economy, the prorated fuel economy, and the calculated fuel

Table 4-4

Fuel Consumed by a High Mileage Vehicle During Potential Purge Times Over LA-4*

LA-4 Hill	Mode (**)	Time (sec)	Distance (miles)	GMC Economy (mpg)***	Prorated Economy (mpg)****	Fuel (gal)
2	A	42	.298	13.9	25.6	.0116
	C	95	1.39	28.7	52.9	.0263
3	A	20	.119	13.6	25.1	.0047
	C	17	.167	29.0	53.5	.0031
4	A	13	.064	11.0	20.3	.0032
5	A	17	.105	12.5	23.0	.0046
	C	27	.261	36.2	66.7	.0039
6	A	19	.072	12.9	23.8	.0030
	C	14	.096	24.9	45.9	.0021
7	A	8	.024	10.2	18.8	.0013
	C	35	.188	20.2	37.2	.0051
8	A	15	.063	12.0	22.1	.0029
9	A	22	.093	14.5	26.7	.0035
10	A	18	.086	13.7	25.3	.0034
11	A	17	.086	13.6	25.1	.0034
	C	163	1.22	32.2	59.4	.0206
12	A	18	.077	13.0	24.0	.0032
	C	32	.219	34.0	62.9	.0035
13	A	18	.090	14.4	26.5	.0034
14	A	22	.088	14.4	26.5	.0033
	C	19	.137	25.4	46.8	.0029
15	A	9	.031	11.9	21.9	.0014
16	A	20	.066	13.7	25.3	.0026
	C	17	.099	27.2	50.1	.0020
17	A	23	.077	13.0	24.0	.0032
	C	23	.160	25.4	46.8	.0034
18	A	14	.054	13.3	24.5	.0022
	Total	757				.1338

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* Potential purge times for this example are the cruise and acceleration modes of LA-4 "Hills" 2-18 (Hill 1 - 125 seconds - is allotted for sensor and catalyst warm-up time).

** A = acceleration, C = cruise. Note: Some hills do not have a cruise mode.

*** Fuel economy values are based on a modal test of an GMC T115 (21.7 mpg - city). These values will vary some between vehicles, but are still useful for approximate calculations.

**** Fuel economy values prorated for a hypothetical vehicle with a city rating of 40 mpg.

consumption, during the allowed purge times in the LA-4. Summing the fuel consumed during these periods, this hypothetical vehicle will consume approximately .13 gallons (360 grams) of fuel. The stoichiometric air consumed during this same period is therefore 5,290 grams.

An acceptable air/fuel ratio perturbation can now be derived by calculating the air/fuel ratio for two extreme cases: a HC laden purge, and a purge with no hydrocarbons (air only purge). The purge volume flow rate is assumed to be constant for both cases.

Preliminary Mass Equations

$$\text{Air}_{\text{Total}} = \text{Air}_{\text{Metered}} + \text{Air}_{\text{Purged}}$$

$$\text{Fuel}_{\text{Total}} = \text{Fuel}_{\text{Metered}} + \text{Fuel}_{\text{Purged}}$$

HC Laden Purge (Purge air/fuel ratio = 1.5, typical for a well-loaded canister)

$$\text{Air}_{\text{Purged}} = 32\text{g} \times 1.5 = 48\text{g}$$

Resulting air/fuel ratio to engine

$$= (\text{Air}_{\text{Total}})/(\text{Fuel}_{\text{Total}})$$
$$= (5290 + 48)/(360 + 32) = 13.6$$

Deviation from stoichiometry

$$= 13.6 - 14.7 = -1.1$$

Air Only Purge

Volume flow rate for HC laden purge

$$= (48\text{g})/(29\text{g/mole}) + (32\text{g})/(58\text{g/mole})$$
$$= 2.2 \text{ moles}$$

Equivalent mass of air

$$= (2.2\text{moles})/(29\text{g/mole}) = 64\text{g}$$

Resulting air/fuel ratio to engine

$$= (5290 + 64)/(360) = 14.9$$

Deviation from stoichiometry

$$= 4.9 - 14.7 = +0.2$$

The total perturbation range is 1.3 air/fuel ratios (14.9-13.6), or ±.65 from the set point. The ±.65 deviation is within a ±1 air/fuel ratio range of authority of the feedback loop which was previously mentioned as already existing in some cars. In this example, the scheduled air/fuel ratio could be set to 15.1, which will still allow rich and lean deviations (due to purge), well within the 14.7 ± 1 range of authority of the fuel control loop. Therefore, shifting the scheduled air/fuel ratio during purge should be sufficient to provide adequate purge control with 11.5 RVP fuel.

As was shown by this theoretical calculation, purging a diurnal and hot soak canister load during an LA-4 should be feasible without causing an increase in exhaust emissions. Since this is a worse case purge condition, the purging of the one-plus hot soak canister load during the FTP should cause even less problems. Therefore, post-1989 vehicles should still be able to certify to their HC emissions standards, despite a change to 11.5 psi RVP certification fuel, with only these minor, purge-related modifications.

5. Summary

This section has discussed the possible canister and purge changes that may be needed due to a change in certification fuel RVP and test procedure. Increases in canister capacity can be accomplished by using improved charcoals, changing the canister configuration, using a heated purge, or most obviously, by increasing the canister size.

While canister size and purge rates are interrelated, changes may also be required in purge rates. However, problems arise with purge when the resulting air/fuel ratio exceeds the capability of the feedback system to maintain stoichiometry. Therefore, purge control is also a key issue.

Improved control for higher RVP certification fuels can be accomplished by a variety of options. Designs may incorporate combinations of both increased canister size and improved purge control. For computer-equipped vehicles, use of a solenoid purge valve with frequency modulation, and possibly a shift of the scheduled air/fuel ratio during purge (both controlled by the onboard computer) was investigated here and shown to be sufficient. None of the necessary changes are expected to incorporate computer hardware changes. The costs of changing the canister and purge control is discussed in the following section.

Non-feedback equipped vehicles, mainly heavier HDVs, are not expected to have as much difficulty meeting their exhaust HC standard with higher RVP fuel. For one reason, the fuel consumption of a HDV is relatively high, so the effect of purge HC on air/fuel ratio will be relatively small. With LDVs and LDTs, the changes in the air/fuel ratio are thought to result in an oxygen deficiency in the catalytic converter, resulting in increased HC emissions. However, since heavy HDVs do not use catalytic converters, this increase can not happen. Also, the HDV exhaust HC standard is less stringent, so they should be able to compensate for any purge-related exhaust HC effect with only calibration changes. However, since heavy HDVs only represent a small portion of the gasoline-fueled HDV fleet, they will not be treated separately in the following cost section. This treatment of heavy HDV vehicles will result in a worse case cost analysis.

II. Costs

A. Vehicle Hardware

This section will describe the method by which EPA has estimated the costs associated with the changes in evaporative control technology previously discussed. The costs described are for the future certification fuel, which will range somewhere between 8.0 and 11.5 RVP. The values for 9.0 RVP only represent the estimated costs for the proposed change in the certification test procedure, since the present certification fuel is 9.0 RVP.

The costs of control are developed as they pass from the vendor to the vehicle manufacturer to the dealer and ultimately to the consumer. The Retail Price Equivalent (RPE) represents the ultimate cost to the consumer and includes all of the markup increases seen along the way. The potential affect of this price increase on vehicle sales is addressed at the end of this section. All prices are presented in 1986 dollars, with adjustments from other years based upon the Consumer Price Index (CPI) for new cars as published in the MVMA 1986 Motor Vehicle Facts and Figures.[9]*

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* Some of the values used in this analysis came from 1983 studies. As indicated by MVMA, the increase in the CPI between 1983 and 1985 is 6.2 percent. Based on this value, the estimated increase in the CPI from 1985 to 1986 is 3.1 percent, for a net increase between 1983 and 1986 of 9.5 percent.

The vendor costs, manufacturer costs, markups, and RPE are summarized for each possible certification fuel (8.0 and 11.5 RVP) in Tables 4-5, 4-6, and 4-7 for LDVs, LDTs, and HDVs, respectively. Since the development and certification costs are assumed to be amortized over a 5 year period, Tables 4-5 through 4-7 show both the short-term costs (within five years), and long-term costs (greater than five years).

1. Vendor Level

In this particular case, "vendor" refers to both the canister manufacturer and the purge control valve manufacturer, both which may be the vehicle manufacturer in some cases. For an increase in certification fuel RVP, the need to build a larger capacity canister and make adjustments to the purge system will lead to certain cost increases. These costs can be divided into: 1) a larger amount of charcoal, 2) larger canister components, 3) retooling, 4) purge control hardware, and 5) revision of the software for the onboard computer. For a decrease in certification fuel RVP, reduction of the canister capacity will incorporate savings for the charcoal and canister components, but will still require a retooling cost. The vendor will also include overhead (20 percent) and profit (20 percent) in the price that is passed on to the vehicle manufacturer.[10]

As the canister size changes, the amount of carbon required will also change with the volume of the canister. The change required for a given certification fuel (8.0 to 11.5 RVP), was developed in section 4.I and is also summarized there in Table 4-3. The charcoal cost used is a vehicle-sales weighted average of the cost of the various types of carbon currently used by vehicle manufacturers. Tables 4-5 through 4-7 show the calculated costs for the increase/decrease in charcoal for each possible certification fuel, (8.0 to 11.5 RVP). The cost reductions for 8.0 and 8.5 RVP are the negatives of the cost increases for 10.0 and 9.5 RVP, respectively, since the change in uncontrolled evaporative emissions is nearly linear in this range. Since the costs associated with all potential changes in RVP are extremely small, the error in this assumption is negligible. All of these costs include the vendor overhead and profit mentioned previously. The details of these cost calculations, except for the markups for overhead and profit, are given in Appendix 4-A at the end of this chapter.

The canister components are assumed to increase in size in proportion to the increase in the total area of the canister. Therefore, they are treated separately from the carbon. The prices for the relevant components: the body, the grid, the filters, the caps, and the connectors have been taken from a

Table 4-5

LDV - Vendor Cost, Manufacturer Costs and Retail Price Equivalent Increases (1986 Dollars)

Short-term Costs (5 years or Less)

Cost Breakdown	Certification Fuel RVP							
	8.0	8.5	9.0	9.5	10.0	10.5	11.0	11.5
Vendor Costs:								
Charcoal*	-.45	-.22	0	.22	.45	.69	.96	1.25
Canister*	-.19	-.09	0	.09	.19	.29	.39	.50
Tooling	.08	.08	0	.08	.08	.08	.08	.08
Valve	0	0	.18	.34	.49	.65	.80	.96
ECU	0	0	.07	.07	.07	.07	.07	.07
Manuf. Costs:	-.56	-.23	.25	.80	1.28	1.78	3.30	2.86
RD&T	.12	.12	.12	.13	.14	.15	.16	.17
Cert.	.71	.71	.71	.71	.71	.71	.71	.71
Subtotal	.27	.60	1.08	1.64	2.13	2.64	3.17	3.74
Profit**	.05	.12	.21	.31	.41	.51	.61	.72
Dealer Costs:	.32	.72	1.29	1.95	2.54	3.15	3.78	4.46
Profit***	.02	.04	.07	.11	.14	.18	.22	.25
RPE	.34	.76	1.36	2.06	2.68	3.33	4.00	4.71

Long-Term Costs (Greater than 5 years)

Cost Breakdown	Certification Fuel RVP							
	8.0	8.5	9.0	9.5	10.0	10.5	11.0	11.5
Vendor Costs:								
Charcoal*	-.45	-.22	0	.22	.45	.69	.96	1.25
Canister*	-.19	-.09	0	.09	.19	.29	.39	.50
Tooling	0	0	0	0	0	0	0	0
Valve	0	0	.18	.34	.49	.65	.80	.96
ECU	0	0	0	0	0	0	0	0
Manuf. Costs:	-.64	-.31	.18	.65	1.13	1.63	2.15	2.71
RD&T	0	0	0	0	0	0	0	0
Cert.	0	0	0	0	0	0	0	0
Subtotal	-.64	-.31	.18	.65	1.13	1.63	2.15	2.71
Profit**	-.12	-.06	.03	.12	.22	.31	.41	.52
Dealer Costs:	-.76	-.37	.21	.77	1.35	1.94	2.56	3.23
Profit***	-.04	-.02	.01	.04	.08	.11	.15	.18
RPE	-.80	-.39	.22	.81	1.43	2.05	2.71	3.41

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* Prices include 40 percent vendor mark-up for overhead and profit.

** A mark-up of 19.2 percent was used for corporate overhead and profit.

*** A mark-up of 5.7 percent was used for dealer profit.

Table 4-6

LDT - Vendor Cost, Manufacturer Costs and Retail Price Equivalent Increases (1986 Dollars)

Short-Term Costs (5 Years or Less)

Cost Breakdown	Certification Fuel RVP							
	8.0	8.5	9.0	9.5	10.0	10.5	11.0	11.5
Vendor Costs:								
Charcoal*	-.62	-.29	0	.29	.62	.95	1.32	1.72
Canister*	-.22	-.10	0	.10	.22	.34	.46	.57
Tooling	.08	.08	0	.08	.08	.08	.08	.08
Valve	0	0	.18	.34	.49	.65	.80	.96
ECU	0	0	.07	.07	.07	.07	.07	.07
Manu. Costs:	-.76	-.31	.25	.88	1.48	2.09	2.73	3.40
RD&T	.22	.22	.22	.24	.25	.27	.29	.31
Cert.	.89	.89	.89	.89	.89	.89	.89	.89
Subtotal	.35	.80	1.36	2.01	2.62	3.25	3.91	4.60
Profit**	.07	.15	.26	.39	.50	.62	.75	.88
Dealer Costs:	.42	.95	1.62	2.40	3.12	3.87	4.66	5.48
Profit***	.02	.05	.09	.14	.18	.22	.27	.31
RPE	.44	1.00	1.71	2.54	3.30	4.09	4.93	5.79

Long-Term Costs (Greater Than 5 Years)

Cost Breakdown	Certification Fuel RVP							
	8.0	8.5	9.0	9.5	10.0	10.5	11.0	11.5
Vendor Costs:								
Charcoal*	-.62	-.29	0	.29	.62	.95	1.32	1.72
Canister*	-.22	-.10	0	.10	.22	.34	.46	.57
Tooling	0	0	0	0	0	0	0	0
Valve	0	0	.18	.34	.49	.65	.80	.96
ECU	0	0	0	0	0	0	0	0
Manu. Costs:	-.84	-.39	.18	.73	1.33	1.94	2.58	3.25
RD&T	0	0	0	0	0	0	0	0
Cert.	0	0	0	0	0	0	0	0
Subtotal	-.84	-.39	.18	.73	1.33	1.94	2.58	3.25
Profit**	-.16	-.07	.03	.14	.26	.37	.50	.62
Dealer Costs:	-1.00	-.46	.21	.87	1.59	2.31	3.08	3.87
Profit***	-.06	-.03	.01	.05	.09	.13	.18	.22
RPE	-1.06	-.49	.22	.92	1.68	2.44	3.26	4.09

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* Prices include 40 percent vendor mark-up for overhead and profit.

** A mark-up of 19.2 percent was used for corporate overhead and profit.

*** A mark-up of 5.7 percent was used for dealer profit.

Table 4-7

HDV - Vendor Cost, Manufacturer Costs and Retail Price Equivalent Increases (1986 Dollars)

Short-Term Costs (5 Years Or Less)

Cost Breakdown	Certification Fuel RVP							
	8.0	8.5	9.0	9.5	10.0	10.5	11.0	11.5
Vendor Costs:								
Charcoal*	-.77	-.38	0	.38	.77	1.19	1.65	2.16
Canister*	-.39	-.20	0	.20	.39	.60	.81	1.04
Tooling	.08	.08	0	.08	.08	.08	.08	.08
Valve	0	0	.18	.34	.49	.65	.80	.96
ECU	0	0	.07	.07	.07	.07	.07	.07
Manu. Costs:	-1.08	-.50	.25	1.07	1.80	2.59	3.41	4.31
RD&T	.49	.49	.49	.55	.61	.67	.73	.79
Cert.	1.74	1.74	1.74	1.74	1.74	1.74	1.74	1.74
Subtotal	1.15	1.73	2.48	3.36	4.15	5.00	5.88	6.84
Profit**	.23	.34	.49	.67	.82	.99	1.16	1.35
Dealer Costs:	1.38	2.07	2.93	4.03	4.97	5.99	7.04	8.19
Profit***	.09	.13	.18	.25	.31	.37	.44	.51
RPE	1.47	2.20	3.11	4.28	5.28	6.36	7.48	8.70

Long-Term Costs (Greater Than 5 Years)

Cost Breakdown	Certification Fuel RVP							
	8.0	8.5	9.0	9.5	10.0	10.5	11.0	11.5
Vendor Costs:								
Charcoal*	-.77	-.38	0	.38	.77	1.19	1.65	2.16
Canister*	-.39	-.20	0	.20	.39	.60	.81	1.04
Tooling	0	0	0	0	0	0	0	0
Valve	0	0	.18	.34	.49	.65	.80	.96
ECU	0	0	0	0	0	0	0	0
Manu. Costs:	-1.16	-.58	.18	.92	1.65	2.44	3.26	4.16
RD&T	0	0	0	0	0	0	0	0
Cert.	0	0	0	0	0	0	0	0
Subtotal	-1.16	-.58	.18	.92	1.65	2.44	3.26	4.16
Profit**	-.23	-.11	.04	.18	.33	.48	.65	.82
Dealer Costs:	-1.39	-.69	.22	1.10	1.98	2.92	3.91	4.98
Profit***	-.09	-.04	.01	.07	.12	.18	.24	.31
RPE	-1.48	-.73	.23	1.17	2.10	3.10	4.15	5.29

---

* Prices include 40 percent vendor mark-up for overhead and profit.

** A mark-up of 19.8 percent was used for corporate overhead and profit.

*** A mark-up of 6.2 percent was used for dealer profit.

1983 draft report entitled, "Manufacturing Costs and Retail Price Equivalent of Onboard Vapor Recovery System for Gasoline-Filling Vapors," prepared by LeRoy Lindgren under contract to the American Petroleum Institute.*[11] This report has been reviewed in a previous document, and the costs have been modified slightly to correct for some arithmetic errors and discrepancies in markups for overhead and profit.[12] The calculations to determine the increased cost for each certification fuel RVP are detailed in Appendix 4-A, and the results are presented in Tables 4-5 through 4-7. These include labor costs, along with markups for vendor overhead and profit.

Retooling costs will also be incurred by the canister manufacturer. Total tooling costs are specified by Lindgren as $0.16 per canister.[11] Complete retooling will not be required, though, since the current canister sizes used on vehicles with relatively large emissions will still be appropriate for many of the vehicles with relatively smaller emissions. Thus, it is assumed that the tooling cost associated with an increase in canister size will be approximately half of this cost, or $0.08 per canister. Due to amortization , the long-term retooling costs incurred by a change in certification fuel will be $0. These costs are summarized in Tables 4-5 through 4-7.

The costs for a purge control valve are shown in Table 4-5 through 4-7. A detailed derivation of the purge control valve required for 11.5 RVP fuel is shown in Appendix 4-A. The valve cost for 9.0 RVP fuel only represents the additional control needed for the proposed change in the certification test procedure. Due to the lack of precise fuel control, carbureted vehicles are less able to quickly and accurately adjust to changes in purged hydrocarbons. Therefore, it is predicted that all of the future carbureted vehicles (an expected 12 percent of the 1990 fleet) will require the frequency modulated solenoid valve to meet the emission standards with the new test procedure on 9.0 RVP fuel. Fuel injected vehicles should not require a valve change for this condition, due to their tighter control of fuel metering. Using a $.80 cost for the existing pneumatic valves typically found on carbureted vehicles,** this hardware change results in an additional cost of $1.50 (case 2.b in Table 4-A-10 in Appendix 4-A). This additional cost for carbureted vehicles results in an average fleet cost of $.18 per vehicle.

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* This report was later updated as the "Revised Report of API/LHI Cost Estimate of Onboard Vapor Recovery System and Review of EPA Technical Report EPA-AA-SDSB-84-01 on Feasibility, Cost, and Cost Effectiveness of Onboard Vapor Control," September 28, 1984. Since the costs cited here were not changed significantly, this analysis continued with the original values.

** A survey was made of the descriptions of emission control systems in the 1985 Mitchell Manuals.[13]

The valve cost for certification fuels between 11.5 and 9.0 RVP was made by linear interpolation. Since the 8.0 or 8.5 RVP certification fuel scenarios would result in a reduction in purge requirements, the use of an improved purge valve is not expected. The valves used for light-duty vehicles should also be adequate for light-duty trucks and heavy-duty vehicles. Therefore, the valve cost for all three classifications are the same.

The proposed purge solenoid valve will be operated by the onboard computer (electronic control unit - ECU). To modify the software for these existing units, a $.07 per-vehicle cost was allocated. This cost is the same as that assumed necessary to modify the software for an onboard refueling vapor control system.[14] No ECU modifications are expected for 8.0 and 8.5 RVP certification fuel.

The sum of the above costs represent the total vendor level costs, which are then passed on to the vehicle manufacturer. However, where the canister manufacturer is the same as the vehicle manufacturer, as it is in many cases here, this is primarily a transfer cost. For an 11.5-psi RVP certification fuel, the total short-term per-vehicle component cost to the vehicle manufacturer is $2.86 for LDVs, $3.40 for LDTs, and $4.31 for HDVs. The long-term cost increases for the vehicle manufacturers only include the increase in hardware costs (charcoal, canister, valve). For an 11.5-psi RVP certification fuel, the total long-term per-vehicle component cost to the vehicle manufacturer is $2.71 for LDVs, $3.25 for LDTs, and 4.16 for HDVs.

2. Manufacturers Level

The vehicle manufacturer must purchase (or transfer) the canister and control technology at the vendor level cost rate. The manufacturer will also face research, development, testing, and certification costs associated with the implementation of the improved technology. There are also corporate overhead and profit that are incorporated into the price that is passed on to the dealer.

Research, development, and testing costs will be incurred by the manufacturer to recalibrate the fuel metering and emission control systems. The additional purge control hardware was included at the vendor level.

Estimates for these costs are difficult to determine. It will be assumed here that, on average, for an 11.5-psi RVP certification fuel standard, 25 vehicle tests, two months of technician time and one month of engineering time will be sufficient to recalibrate each engine-evaporative family combination. Testing costs for LDVs and LDTs were obtained from earlier EPA work on light-duty certification costs.[15] For HDVs, the cost used here was that determined in the previous HDE rulemaking which instituted HDV evaporative HC controls.[16] It is further assumed that this cost is proportional to the control required. A vehicle acquisition cost, held constant for all levels of control, is also included.[12] This methodology is detailed more in Appendix 4-A.

The research, development and testing costs (RD&T) for LDVs, LDTs, and HDVs are summarized in Tables 4-5, 4-6, and 4-7, respectively. The costs for RD&T were adjusted for 2 years of development time at 10 percent interest, and then amortized over 5 years to reflect the spreading out of payments by the manufacturer. For an 11.5-psi RVP certification fuel, this yields $.17/vehicle for LDVs, $.31/vehicle for LDTs, and $.79/vehicle for HDVs. Since all RD&T costs will be recovered over a 5 year period, the RD&T costs will be $0 on a long-term base.

Manufacturers of LDVs, LDTs, and HDVs will incur a cost to certify their fleets with a new certification fuel. The LDV/LDT costs were obtained from the EPA work previously cited.[12] Because year to year carryover of engine families is not 100 percent, only 90 percent of the LDV/LDT recertification costs would be attributable to this change. Including one year of opportunity cost at 10 percent and then amortizating over 5 years results in a $.71/vehicle LDV and $.89/vehicle LDT cost impact. The HDV certification costs are based on a previous Regulatory Impact Analysis and a Regulatory Support Document.[17,18] Following the same discounting and amortization procedure, the resulting cost is $1.74/vehicle. The development details for the LDV/LDT/HDV certification costs are shown in Appendix 4-A. As with RD&T costs, there are no long-term price increases due to certification costs.

Before passing on the cost to the dealer, the vehicle manufacturer will add markups for corporate overhead and profit. The total manufacturer markup according to the vehicle type (LDV, LDT, HDV) were determined under a contract to Jack Faucett Associates [19], and are respectively footnoted in Tables 4-5 through 4-7. These markups are applied to the sum of the total vendor level costs, the research and development costs, and the certification costs.

The total cost at the manufacturer level, then, is the sum of the hardware, development, certification, and markup costs. It is assumed that no significant retooling will be required at the assembly level -- only at the canister manufacturing level.

3. Dealer Level

The total increase in cost seen by the dealer is shown in Tables 4-5 through 4-7. The dealer is expected to make a reasonable profit from the sale of a vehicle. Therefore, a markup which recovers incremental costs and yields a fair return on incremental investment must be included in the total cost. This markup was also developed under the previously mentioned contract to Jack Faucett Associates.[19] The dealer markups are footnoted in each table and ranged from 24.9 to 26.0 percent.

4. Consumer Level (Retail Price Equivalent)

The bottom lines of the short-term and long-term sections of Tables 4-5 through 4-7 show the increase in cost expected to be seen by the consumer. The resulting short-term RPE increase associated with a change to an 11.5-psi RVP certification fuel is $4.71/vehicle for LDVs, $5.79/vehicle for LDTs, and $8.70/vehicle for HDVs. The resulting long-term RPE increase associated with a change to an 11.5-psi RVP certification fuel is $3.41/vehicle for LDVs, $4.09/vehicle for LDTs, and $5.29/vehicle for HDVs.

5. Impact on Vehicle Sales

Substantial changes in vehicle price do affect vehicle sales. A typical model to calculate the impact on vehicle sales is the price elasticity of demand. However, a 0.05 percent change in price ($4.71 change for a $10,000 light-duty vehicle) is too insignificant to be accurately handled by this model. In any event, the EPA expects a $4.71 to $8.70 change in price (LDV to HDV), to have a negligible effect on vehicle sales. This price increase should especially be of little consequence in relation to annual price increases occurring at the time of a new model year introduction.

B. Effects of Increased Canister Size on Operating Costs

There will be a very slight reduction in fuel economy associated with the increased weight of the canister in the modified evaporative control system. This will affect a vehicle's operating cost, and must therefore be included in the total costs associated with the proposed changes to the certification test procedure. Key values used in the calculation of this weight penalty are summarized in Table 4-8.

Table 4-8

Summary of Values Used in Calculation

	LDV	LDT	HDV
Fuel Economy (mpg)*	23.19	17.72	9.208
Vehicle Weight (lb)**	3082	3832	9270
Weight Sensitivity Factor (% change in fuel economy per % change in weight)***	0.329	0.402	0.450
Discounted Lifetime Mileage****	65,400	80,900	71,700

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* 1985 values from "MOBILE3 Fuel Consumption Model," Mark A. Wolcott, EPA, and Dennis F. Kahlbaum, CSC, September 1985.

** "Light-Duty Auto Fuel Economy...Trends Through 1985," Heavenrich, Murrell, Cheng and Loos, SAE 850550.

*** "Analysis Memorandum: Design Factor Update," prepared by Energy and Environmental Analysis, Inc., for EPA, October 1, 1982.

**** "Regulatory Impact Analysis, Oxides of Nitrogen Pollutant Specific Study and Summary and Analysis of Comments," EPA/OAR/OMS, March 1985. (Discounted at 10 percent over life of vehicle.) [Reference 17 of Chapter 4.]

Appendix 4-A describes how the component costs for each certification fuel RVP were calculated. The weight associated with each component of an 850-ml canister is given in Table 4-A-5. By scaling up these component weights, as was done for the costs (described in Appendix 4-A), the increased canister weight associated with each certification fuel RVP can be determined. These are provided in Table 4-9.

These weight increases can be expressed as a percentage of the total weight of the vehicle using the estimates of total vehicle weights shown in Table 4-8. Estimated weight sensitivity factors, which relate a percentage increase in weight to a percentage reduction in fuel economy, and class-average fuel economies are also given in Table 4-8 and are used along with the percentage weight increases to determine the expected reductions in fuel economy.

In their comments to the November 1985 study, GM took exception to some of the values which were used in the calculation.[20] GM stated that a "weight compounding" factor of 1.7 should be applied to the additional canister weight to account for "additional weight in the structure and powertrain in order to maintain equivalent structural integrity and vehicle performance." While recognizing the validity of weight compounding in general, it does not seem practical that the added one to two pounds to the canister will have any farther reaching affects than possibly to the bracketing which holds it in place.[21] Thus, as can be seen in Table 4-9, a weight compounding factor of 1.1 has been added to account for possible small changes in bracketing.

In addition to the weight compounding factor, GM also took exception to the 0.329 weight sensitivity factor used for light duty vehicles. They instead promoted a factor of 8.5 gallons/10,000 mi/100 lbs. which is approximately equivalent to a 0.608 weight sensitivity factor depending on the vehicle weight and fuel economy chosen. The GM factor is made up of three components: 1) a factor recognizing the differences in vehicle inertia (about 55 percent of the total), 2) a factor to account for increases in rolling resistance (about 15 percent), and, 3) a factor to account for necessary changes in vehicle performance (about 30 percent). The first portion attributable to inertia effects and the 0.329 EPA sensitivity factor are very close in magnitude, even though the EPA factor may also have taken into account much of the rolling resistance which GM added separately. The EPA value was based on a much larger and broader data set (over 5,000 cars of 1975 through 1981 model years from more than 20 different manufacturers), and therefore should prove to be more reliable. In addition, since road load may have been increased with inertia weight settings during testing, the rolling resistance should not be factored in separately.[21]

Table 4-9

1985 Vehicle Weight Penalty Associated with Various Certification Fuels

Certification Fuel RVP's (psi)

	8.0	8.5	9.0	9.5	10.0	10.5	11.0	11.5
LDV								
Increased Weight (lb)	-0.35	-0.16	0	0.19	0.45	0.66	0.88	1.19
Adjusted weight (x1.1)	-0.385	-0.176	0	0.209	0.495	0.726	0.979	1.309
Reduced Fuel Economy (gal/mi x 10^{-6})	-1.766	-.807	0	0.958	2.270	3.329	4.490	6.003
Extra Fuel (gal/useful life)	-0.115	-0.053	0	0.063	0.148	0.218	0.294	0.393
Cost ($/vehicle)	-0.094	-0.043	0	0.052	0.121	0.179	0.241	0.322
LDT								
Increased weight (lb)	-0.45	-0.22	0	0.26	0.58	0.88	1.21	1.56
Adjusted weight (x 1.1)	-0.495	-0.242	0	0.286	0.638	0.968	1.331	1.716
Reduced Fuel Economy (gal/mi x 10^{-6})	-2.93	-1.433	0	1.693	3.777	5.731	7.881	10.160
Extra Fuel (gal/useful life)	-0.237	-0.116	0	0.137	0.306	0.464	0.638	0.822
Cost ($/vehicle)	-0.194	-0.095	0	0.112	0.251	0.380	0.523	0.674
HDT								
Increased weight (lb)	-0.62	-0.32	0	0.41	0.81	1.25	1.70	2.20
Adjusted weight (x 1.1)	-0.682	-0.352	0	0.451	0.891	1.375	1.870	2.420
Reduced Fuel Economy (gal/mi x 10^{-6})	-3.596	-1.856	0	2.378	4.697	7.249	9.859	12.758
Extra Fuel (gal/useful life)	-0.258	-0.133	0	0.170	0.337	0.520	0.707	0.915
Cost ($/vehicle)	-0.212	-0.109	0	0.139	0.276	0.426	0.580	0.750

The final portion of GM's sensitivity factor is a significant amount for a "performance adjustment." Based on EPA's own data, GM's performance adjustment, if it was applicable, is only nearly half of what would be appropriate. However, just as it seems unreasonable to allow for weight changes to the vehicle structure and power train for at most a 1 to 2 pound increase in canister weight, it also seems unreasonable to think that a manufacturer would change the size of future engines to correct for such a small loss in performance.[21] Thus it does not appear appropriate to change the 0.329 weight sensitivity factor from the previous analysis.

To further quantify the weight penalty, the reductions in fuel economy calculated using the weight sensitivity factors are then coupled with estimates of lifetime vehicle mileages (shown in Table 4-8) to calculate the extra gallons of fuel used over the vehicle's life. These lifetime mileages are discounted (at 10 percent per annum) to represent the fact that a dollar saved in the tenth year of vehicle use is not the same as one saved in the first year. The net cost to the consumer is then determined using a fuel cost of $0.82 per gallon. Table 4-9 summarizes the calculated values for reduction in fuel economy, extra gallons of fuel, and cost.

The costs shown in Table 4-9 are accurate for the 1985 model year, as the calculations were performed on 1985 data. Since vehicle fuel economy is expected to increase in the future, these costs thus represent a worst case situation. Accurate estimates of future costs can not be made since although there are future fuel economy estimates, there are no accurate future vehicle weight estimates. Since future vehicle weight is expected to decrease while fuel economy increases, assuming current vehicle weights for the future would severely under estimate the weight penalty costs.

C. Body Modification Costs

Section I estimated that roughly a 60 percent increase in canister volume may be required to achieve control of evaporative emissions from vehicles designed for 11.5 RVP fuel. The question has been raised as to whether current engine compartments could accommodate canisters that were 60 percent larger than those presently being used. A number of industry sources have claimed that extensive and costly vehicle modifications would be required if manufacturers were forced to certify using higher RVP fuel. However, upon further investigation, it appears that the problem is neither as widespread nor as difficult to solve as it has been pictured, and that in the vast majority of cases, canisters large enough to handle evaporative emissions from 11.5 RVP fuel (worse case) could be accommodated without vehicle modifications. For even the most difficult situations, there are a number of options open for the manufacturer to gain the necessary additional capacity without incurring costs for modifying the vehicle.

First of all, not all vehicles will require larger canisters. Some vehicles, particularly those with smaller fuel tanks, may already have excess canister capacity. Most manufacturers make only two or three canister sizes to service their entire vehicle line, so that a canister with sufficient capacity for a mid-size car with a V-6 engine may also be used for a 4-cylinder vehicle with a much smaller fuel tank. Then too, the growing trend toward fuel injection means that less canister capacity will be required for most applications, due to the typical decrease in hot soak emissions from fuel-injected vehicles.

Those vehicles that do require additional capacity may not need to physically increase canister size. For example, some manufacturers could gain the additional adsorptive capability needed for the higher RVP fuel by switching to charcoal with a greater specific working capacity than they are currently using. Of course, this option would not be available to the industry as a whole, since some manufacturers already use charcoal with a high specific working capacity. These manufacturers may find it necessary to increase their current canister volumes by up to 60 percent. However, as will be seen below, there is ample room in most engine compartments for the relatively modest increases required. The actual increases required in canister dimensions are smaller than might be expected. For example, a cylindrical canister of approximately 2 liters capacity (roughly 5" in diameter and 6 1/4" long) would require only a 1 3/8" increase in diameter (28 percent) to increase the volume to 3.2 liters. Similarly, a one liter rectangular canister, such as might be used in a subcompact or compact, with dimensions of 2 inch (") by (x) 5" x 6" would only require a 60 percent increase in the smallest dimension (i.e., from 2" to 3.2").

For those vehicles with crowded engine compartments where increasing the size of the canister might be more difficult, there are also a number of options available. Baffles could possibly be used to change the effective length to diameter ratio. Or, the actual shape of the canisters could be changed to fit the available space. A change from a cylindrical to a rectangular canister of the same dimensions, for example, results in a 27 percent increase in volume with a slightly less increase in capacity. Finally, for the relatively few worst-case situations the canister could be relocated or a multiple-canister approach could be used.

As a rough gauge of whether current vehicle designs could accommodate canisters that were 60 percent larger than those now in use, a spot check was made of the space available for canisters in a number of late-model vehicles. An attempt was made to identify the configurations where available space was likely to be most limited. Those included (1) subcompact or compact vehicles, particularly those with the short, close-quarter engine compartments associated with transverse front-wheel-drive (FWD) powertrains, (2) so-called pony cars, i.e., small sporty vehicles with large engines, (3) mid-size or full-size vehicles equipped with a multitude of engine-driven options, including turbochargers, air conditioning and fuel injection pumps, as well as the more usual power steering, power brakes, and air pumps.

Accordingly, a sample of nine vehicles was selected, including four compacts (two of which were just barely over the subcompact dividing line), three full size or mid-size cars with many options, including fuel injection and turbocharging, and one pony car. No LDTs were inspected, since there is ample room in most LDT engine compartments for a much larger increase in canister volume than would be required for 11.5 RVP fuel. However, one FWD mini-van with a forward-located engine was checked, again representing a configuration with the most limited space under the hood.

The vehicles selected consisted of three Ford, three Chrysler and three GM models; six of the vehicles were FWD with transverse engines. Four of the vehicles were carbureted and five were fuel injected. One of the vehicles was turbocharged. Five vehicles were powered by 4-cylinder engines while four were equipped with V6 or V8 engines. On five of the vehicles the evaporative canisters were mounted in the engine compartment, while on the remainder (three Chrysler products and one Ford) the canister was mounted in the front fender ahead of the wheel well. The latter location made it somewhat difficult to obtain exact canister measurements, however, it was possible to get a rough approximation of the dimensions and resultant volumes. It should also be noted that access to canisters located inside the engine compartment was also difficult in many cases, due to the canisters being located under alternators, air conditioning compressors, etc. However, difficulty of access did not necessarily equate to lack of room for increasing canister size.

The results of the survey are shown in Table 4-10. In general, there appears to be room for the required increases in canister volume in all the vehicles surveyed. As might be expected, the subcompact designs would present more of a problem than the larger designs. However, it should be pointed

Table 4-10

Results of Evaporative Canister/ Engine Compartment Survey

Vehicle/Engine	Approximate Canister Size	Approximate Capacity	Notes*	Space for Larger Canister ?
Lynx 1.6L 4	2" x 5" x 5 1/2"	.9L	F,R	yes, but tight
Sable 3.0L V-6	2" x 5" x 5 1/2"	.9L	E,I,R	yes
LTD 5.0L V-8	3" x 7 1/2" x 10"	3.7L	F,I,R	yes
Sundance 2.2L 4	5" x 5 1/2"	1.8L	C,F	yes, but tight
LeBaron 2.2L 4	5" x 5 1/2"	1.8L	C,F,T	yes
Voyager 2.2L 4	5" x 5 1/2"	1.8L	C,F	yes
Nova 1.6L 4	5 1/2" x 3 1/2"	1.3L	C,E	yes, but tight**
Camaro 2.8L V-6	5" x 5 1/2"	1.8L	C,E	yes
Celebrity 2.8L V-6	5" x 5 1/2"	1.8L	C,E,I	yes

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* Explanation of Notes:

C - Cylindrical canister
E - Canister located in engine compartment
F - Canister located in fender ahead of wheel well
I - Fuel injected
R - Rectangular canister
T - Turbocharged

** Would need small increase in both diameter and length for 60 percent volume increase.

out that the canisters on these vehicles are smaller and would require proportionally smaller size increases for a 60 percent volume increase. The necessary increases in dimensions are feasible for most of the vehicles surveyed; only the smallest compacts might require a change in more than one major canister dimension due to available space constraints. For example, the Nova, which has a short cylindrical canister approximately 5 1/2" in diameter and 3 1/2" long, would require either a 1 1/2" increase in diameter or a 2 1/8" increase in length to gain 60 percent more volume. Due to the cramped quarters where the canister is currently located, either of those increases by itself might present a problem. However, a 1" increase in diameter and a 1/2" increase in length would result in 60 percent more volume. Alternatively, a rectangular canister of 5 1/2" x 5 1/2" x 4 1/2" would also provide the necessary increase, since almost 27 percent of the additional 60 percent could be obtained by switching from a cylindrical canister to a rectangular canister of the same dimensions. The 1" increase in length would provide the additional capacity required in this particular application.

Thus, it appears that few if any vehicles will require modifications to accommodate canisters suitable for 11.5 RVP fuel. Some vehicles may not need to increase canister size at all, either due to excess capacity in current designs or as a result of switching to charcoal with higher specific adsorptive capacity. If it should be necessary to increase canister size, there is ample room in most engine compartments for the relatively modest size increases that would be required. For those relatively few cases where the required additional capacity could not be achieved through a relatively small increase in one or more canister dimensions, there are other options such as shaping the canister to fit the available space, canister relocation, or switching to a multiple-canister configuration. The cost for body modifications is therefore assumed to be zero.

III. Conclusions

A worse case or minimal R&D approach was taken in this analysis. The methods that may be required to increase storage capacity and purge control appear to be feasible with current technology. No significant effects upon vehicle performance other than reduced evaporative emissions are expected from these changes. In the most extreme case of an 11.5-psi RVP certification fuel, the maximum final cost to the consumer at the time of vehicle purchase has been estimated as $4.71/vehicle for LDVs, $5.79/vehicle for LDTs, and $8.70/vehicle for HDVs. By amortizing the development and certification costs over a 5 year period, the final cost to the consumer will be reduced to an estimated $3.41/vehicle, $4.09/vehicle, and $5.29/vehicle for LDV, LDT, and HDV, respectively.

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Appendix 4-A

Detailed Derivation of Evaporative ECS Component Costs

This appendix details the calculations used to derive the evaporative emission control system (ECS) costs discussed in Chapter 4. The first section will describe how the average canister sizes for current evaporative control systems were determined. This will be followed by sections discussing: 1) canister material costs, 2) purge control valve costs, 3) research, development and testing costs, and 4) certification costs associated with the changes in the certification test procedure.

Average Canister Sizes in Current Vehicles

The average canister sizes for current vehicles were calculated by using a sales-weighted average of the canister sizes currently in use. Only the major manufacturers -- GM, Ford, Chrysler, Toyota, and Nissan -- were considered in this calculation. These manufacturers represent 83 and 90 percent of the total 1983 gasoline light-duty vehicle (LDV) and gasoline light-duty truck (LDT) market, respectively.

Table 4-A-1 shows the canister sizes used by each manufacturer for various engine families. Table 4-A-2 combines these values into a single value for light-duty vehicles and light-duty trucks for each manufacturer, assuming equal sales per engine family. A forecasted 1990 normalized market share was generated as described and shown in Table 4-A-3. Using these market shares for the five manufacturers, a sales-weighted average canister size for each vehicle class is determined. These industry-wide average canister sizes are summarized in Table 4-A-4. As indicated in the table, the average canister size for heavy-duty gasoline-fueled vehicles is taken as the current size for GM vehicles, as GM dominates this market (i.e., two-thirds of sales).

Canister Material Costs

This section details the methodology used to determine the costs associated with changing the canister size. These costs will be determined for each potential certification fuel RVP.

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* Reference 11 in Chapter 4. A final version of the report has since become available, but the changes were not significant so the calculations were not redone.

Table 4-A-1

Canister Distribution

Manufacturer	Canister Size (ml)	Number of Families LDV*	LDT*
GM	1500	29	2
GM	2500	–	5
GM	2500 + 300	–	1
Ford	925	7	8
Ford	1400	3	7
Ford	1400 + 1400	1	–
Chrysler	1320	4	1
Chrysler	1790	3	6
Chrysler	1320 + 1320	–	4
Toyota	835	2	1
Toyota	845	1	–
Toyota	1400	1	1
Toyota	1400 + 645	–	1
Nissan	580	6	3
Nissan	1230	2	–

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* 1983 Model Year.

Table 4-A-2

Average Canister Size by Manufacturer

Vehicle Class	Manufacturer	Avg. Canister Size for 9.0 RVP Fuel (ml)*
LDV	GM	1500
LDV	Ford	1225
LDV	Chrysler	1521
LDV	Toyota	979
LDV	Nissan	743
LDT	GM	2288
LDT	Ford	1147
LDT	Chrysler	2059
LDT	Toyota	1427
LDT	Nissan	580

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* Average of 1983 MY canisters assuming equal sales of evap. families.

Table 4-A-3

Market Shares by Manufacturer

Vehicle Class	Manufacturer	1983 Normalized* Market Share (%)	1990 Normalized** Market Share (%)
LDV	GM	45.74	46.81
LDV	Ford	17.78	18.20
LDV	Chrysler	9.56	9.78
LDV	Toyota	13.89	13.00
LDV	Nissan	13.03	12.21
LDT	GM	41.98	40.86
LDT	Ford	34.76	33.84
LDT	Chrysler	10.12	9.85
LDT	Toyota	7.29	8.57
LDT	Nissan	5.85	6.88

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* Normalized on the basis of 100 percent of the domestic LDV and LDT market is shared by GM, Ford and Chrysler, and 100 percent of the imported LDV and LDT market is shared by Toyota and Nissan.

** Normalized as for 1983. Manufacturers' shares of domestic or imported market is assumed to be the same as for 1983, but the ratio of imported to domestic registrations changed in accordance with projections made in Reference 23 of Chapter 4.

Table 4-A-4

Industry-Wide Average Canister Size*

Vehicle Class	Avg. Canister Size for 9.0 RVP Fuel (ml)
LDV	1292
LDT	1688
HDG	4000**

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* Uses 1989 Market Shares.

** Average canister size used by GM, based on certification records for the 1985 model year.

Table 4-A-5 shows the canister material costs to vendors taken from a draft report prepared for API by LeRoy Lindgren.* The costs presented are for an 850 ml GM canister, which is smaller than the average canister sizes for current LDV, LDT and HDV classes shown in Table 4-A-4.

Table 4-A-6 shows these material costs after they have been scaled up to the average canister sizes for LDV, LDT and HDV families. The charcoal costs were increased in proportion to the increase in volume of the canisters. The body, grid, filter and cap costs were increased in proportion to the increase in surface area of the canister. (For cylinders which have the same length-to-diameter ratio, the ratio of surface areas is equal to the ratio of volumes to the two-thirds power.) The connector cost is independent of the canister size and therefore remains constant.

The charcoal costs per unit volume were calculated on a 1990 vehicle sales-weighted basis (see Table 4-A-3). GM and Chrysler are assumed to continue to use wood-based charcoals (price = $1/lb, density = .26-.30 g/ml) whereas Ford, Nissan, and Toyota are assumed to continue to use coal-based charcoals (price = $2/lb., density = .37-.38 g/ml). Tables 4-A-7, 4-A-8, and 4-A-9 contain the canister material cost increases to meet a higher RVP certification fuel for LDVs, LDTs and HDVs, respectively. The increases in volume required for each higher RVP certification fuel are listed in Table 4-3 and the increases in canister surface area can be determined from the volume ratios (as stated earlier). The increases in costs were calculated by exactly the same method as was used above to scale up the 850-ml GM canister to the average canister sizes for each class of vehicle. The charcoal and canister savings for 8.0 and 8.5 RVP fuels are assumed to equal the charcoal and canister cost increases for 10.0 and 9.5 RVP fuels, respectively.

Purge Control Valve Costs

The proposed purge control valves were described in Chapter 4. In summary, the valves are to slowly initiate any increases in purge rate and to vary the purge flow rate according to engine conditions. To accomplish this type of control, two types of valves were proposed: a pneumatic diaphragm valve, and an electric solenoid valve with frequency modulation.

Existing purge systems vary the purge rate according to air flow to the engine. Most of these systems allow purging only during cruise or acceleration conditions, when the engine is above a minimum rpm, and after the engine has had time to

Table 4-A-5

Canister Material Cost to Vendor (Dollars)*

Component Description	Material	Weight (lbs.)	Material Costs ($)**
Body	DB437	.30	.27
Grid	G7	.10	.04
Int. Filter	AY332	.10	.11
Ext. Filter	KZI-4	.20	.23
Charcoal	54448	.50	.55
Cap	DB437	.10	.09
Connectors	DB437	.05	.04
TOTAL			1.33

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* Taken from Reference 11 of Chapter 4.

** Material costs are those for an 850-ml GM canister and were converted to 1986 dollars from 1983 dollars, using a net increase of 9.5 percent.

Table 4-A-6

Baseline* Canister Material Costs to Vendor (1986 Dollars)

Component Description	Vehicle Class		
	LDV	LDT	HDV
Body	.35	.41	.74
Grid	.05	.06	.12
Int. Filter	.14	.17	.30
Ext. Filter	.30	.35	.63
Charcoal**	1.48	2.04	2.55
Cap	.12	.14	.23
Connectors	.04	.04	.04
TOTAL	2.48	3.21	4.61

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* Baseline refers to the average canister sizes for 9.0 RVP fuel shown in Table 4-A-4.

** Charcoal cost is the 1990 sales-weighted average cost of the different types of charcoals. Wood-based charcoal ($1/lb) is used by GM and Chrysler and coal-based charcoal ($2/lb) is used by Ford, Nissan, and Toyota.

NOTE: Body, filter, grid, and cap costs increase in proportion to the surface area and charcoal cost increases in proportion to the volume. (Canister length-to-diameter ratio is assumed to remain constant.) Connector cost is independent of the canister volume, thus there is no increase in material cost to the vendor for connectors for larger canisters.

Table 4-A-7

LDV Canister Material Cost Changes at Vendor Level* (1986 Dollars)

Component Description	Certification Fuel RVP (psi) 8.0	8.5	9.5	10.0	10.5	11.0	11.5
Body	-.05	-.02	.02	.05	.07	.10	.13
Grid	-.01	.00	.00	.01	.01	.01	.02
Int. Filter	-.02	-.01	.01	.02	.03	.04	.05
Ext. Filter	-.04	-.02	.02	.04	.06	.09	.11
Charcoal	-.32	-.15	.15	.32	.50	.68	.90
Cap	-.02	-.01	.01	.02	.03	.03	.04
TOTAL	-.46	-.21	.21	.46	.70	.95	1.25

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* Does not include 40-percent vendor mark-up for overhead and profit. No change is needed at 9.0 RVP.

Table 4-A-8

LDT Canister Material Cost Increase at Vendor Level* (1986 Dollars)

Component Description	Certification Fuel RVP (psi) 8.0	8.5	9.5	10.0	10.5	11.0	11.5
Body	-.06	-.03	.03	.06	.09	.12	.15
Grid	-.01	.00	.00	.01	.01	.02	.02
Int. Filter	-.02	-.01	.01	.02	.04	.05	.06
Ext. Filter	-.05	-.02	.02	.05	.07	.10	.13
Charcoal	-.44	-.21	.21	.44	.68	.94	1.23
Cap	-.02	-.01	.01	.02	.03	.04	.05
TOTAL	-.60	-.28	.28	.60	.92	1.27	1.64

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* Does not include 40-percent vendor mark-up for overhead and profit. No change is needed at 9.0 RVP.

Table 4-A-9

HDV Canister Material Cost Increase at Vendor Level* (1986 Dollars)

Component Description	Certification Fuel RVP (psi)						
	8.0	8.5	9.5	10.0	10.5	11.0	11.5
Body	-.10	-.05	.05	.10	.16	.21	.27
Grid	-.02	-.01	.01	.02	.03	.03	.04
Int. Filter	-.04	-.02	.02	.04	.06	.09	.11
Ext. Filter	-.09	-.04	.04	.09	.13	.18	.23
Charcoal	-.55	-.27	.27	.55	.85	1.18	1.54
Cap	-.03	-.02	.02	.03	.05	.07	.09
TOTAL	-.83	-.41	.41	.83	1.28	1.76	2.28

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* Does not include 40-percent vendor mark-up for overhead and profit. No change is needed at 9.0 RVP.

warm-up. A few systems that purge to the air cleaner (which provides a vacuum source proportional to engine air flow), do not use control valves. Most systems purge to the throttle housing or to the intake manifold. These locations provide greater vacuum, but inversely proportional to air flow. Therefore, all of these systems require some type of purge control.

The existing purge control valves use pneumatic, electric, or combined pneumatic/electric systems. The pneumatic systems vary from simple on/off valves, to two-stage valves, to more elaborate pneumatic purge control systems which will even switch the vacuum source. The pneumatic control valves are typically integral with the canister housing, but may be of independent construction.

The electric systems are usually solenoids which may be simple on/off valves, or two-stage orifice controls. Some manufacturers are starting to use frequency modulated solenoid valves, which is the same type as that assumed here for use here on the majority of vehicles at 11.5 psi RVP. Their present use indicates the feasibility of incorporating them into a purge control system, and that the associated cost is not inhibiting. The solenoid valves are controlled by the onboard computer. Some hybrid pneumatic/electric purge systems use an on/off solenoid in the pneumatic signal line to prevent purging during unwanted conditions.

Table 4-A-10 shows the cost for existing purge control systems, the cost for the corresponding proposed system, and the cost differences. Using certification records and the Mitchell Manual[13] the various existing systems were grouped into one of four general categories or cases: 1) no control valve; 2) pneumatic valve; 3) solenoid valve; 4) pneumatic/solenoid valves. The number of vehicles with modulating solenoid valves were few and therefore were included in the on/off solenoid category.

The cases in Table 4-A-10 with either no control valve or a pneumatic valve are matched with both proposed systems to allow cost comparison. The proposed modulating solenoid valve is assumed to be the logical replacement for the two cases already incorporating solenoid valves. This assumption incorporates the existing development inertia, and the improved purge control inherent with computerized systems.

The costs shown in Table 4-A-10 are based on over-the-phone estimates of the vendor sale price from Borg-Warner Automotive. Due to the large number of similar systems amongst engine families, a large volume production (1 million units) was assumed. The $0.80 pneumatic valve price

Table 4-A-10

Proposed Purge Control Systems

Case	Existing System (Cost)*		Proposed System (Cost)*		Add'l System Cost
1.a			Proportional Valve	($1.60)	
	No Control Valve		Delay Valve**	$1.00)	
	Subtotal	$0	Subtotal	(2.60)	$2.60
1.b	No Control Valve		Modulating Solenoid	($2.30)	
	Subtotal	$0	Subtotal	$2.30	$2.30
2.a			Proportional Valve	($1.60)	
	Pneu. Valve	($0.80)	Delay Valve**	($1.00)	
	Subtotal	$0.80	Subtotal	$2.60	$1.80
2.b	Pneu. Valve	($0.80)	Modulating Solenoid	($2.30)	
	Subtotal	$0.80	Subtotal	$2.30	$1.50
3.	Solenoid	($2.00)	Modulating Solenoid	($2.30)	
	Subtotal	$2.00	Subtotal	$2.30	$0.30
4.	Pneu. Valve	($0.80)			
	Solenoid	($2.00)	Modulating Solenoid	($2.30)	
	Subtotal	$2.80	Subtotal	$2.30	-$0.50***

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* Valve costs are for high production volumes (1 million). Values based on phone conversations with engineers at Borg-Warner Automotive, August 1-4, 1986.

** Delay valve retards the vacuum signal that opens the proportional valve.

*** The automotive industry automatically takes advantage of cost saving changes on their own. Therefore, rather than incorporating in a cost credit for a modification that will happen, the EPA will consider the additional system cost for case 4 to be $0.

was estimated by the EPA from the reported $1.35 price for an independently constructed two-stage valve. The reduced price should be more representative of the common construction of integrating the body of the purge valve in with the canister housing. The $.30 difference in price between existing solenoid valves and the proposed frequency modulated solenoid valves incorporates a dampening capability for pulse control. The cost for a delay valve was expressed as being under $1.00, but $1.00 was used to be conservative. The price for the proportional valve was a Borg-Warner estimate for a valve that was developed, but never put into production.

The additional system cost for the modulating solenoid valve is $.30 less than the proposed proportional/delay valve system. Due to this economic advantage, along with the improved purge control available, this study will assume that frequency modulated solenoid valves will become common throughout the fleet for high volatility purge control.

Table 4-A-11 shows an estimate of the average fleet costs for changing to the proposed purge control system. The vehicles shown are categorized according to the cases presented in Table 4-A-10. The fleet weighting is based on 1985 sales of these Chrysler, General Motor, and Ford vehicles, as reported in the 1986 Ward's Automotive Yearbook.[22] While these vehicles only represent 54 percent of the 1985 gasoline LDV fleet, any error associated with calculating the average fleet cost will be small, considering a $2.30 range of options for the cost of the proposed valve change. The average fleet hardware cost for the proposed change to frequency modulated solenoid valves for purge control was therefore estimated at $0.96 per vehicle.

Research, Development and Testing Costs

Table 4-A-12 contains a summary of the research, development and testing (RD&T) costs for a change in certification fuel to an RVP of 11.5 psi. The various costs of RD&T per engine family are broken down in Table 4-A-10 and costs for each component were estimated using engineering judgment. The total cost was calculated using the total number of engine families from 1984 certification records. The total cost was adjusted for 2 years of interest at 10 percent, and then amortized five years. This amount was then used to determine the cost per vehicle based upon projected 1989 sales.

To obtain the RD&T costs for a change in the certification fuel to an RVP between 9.0 psi and 11.5 psi, the vehicle acquisition costs were held constant and the salary and testing costs were varied linearly. The RD&T costs for 8.0 and 8.5 RVP

Table 4-A-11

Estimate of Fleet Cost for Changing Purge Control System

Manufacturer/ Engine Size	Case*	Cost ($)	1985 Sales**	Total Cost ($)
Chrysler				
2.2ℓ	3	0.30	894,394	268,318.20
5.2ℓ	4	0	168,238	0
GM				
2.5ℓ	2.b	1.50	689,530	1,034,295.00
2.8ℓ	4	0	615,328	0
3.8ℓ	3	0.30	683,578	205,073.40
5.0ℓ	2.b	1.50	1,111,823	1,667,734.50
Ford				
1.9ℓ	2.b	1.50	209,200	313,800.00
2.3ℓ	1.b	2.30	478,225	1,099,917.50
3.8ℓ	3	0.30	435,519	130,665.70
5.0ℓ	2.b	1.50	617,490	926,235.00
Total			5,903,325***	$5,646,039.30

Average Fleet Cost = $5,646,039.30/5,903,325 = $0.96/vehicle

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* These cases refer to the case presented in Table 4-A-10.

** 1985 Sales obtained from the 1986 Ward Manual [Reference 22 of Chapter 4.]

*** This value represents 54 percent of the 10,947,224 gasoline light-duty vehicle sales for 1985.

Table 4-A-12

Research, Development and Testing (RD&T) Costs Summary (1986 Dollars)

LDV/LDT: ($/family)

Vehicle Acquisition	17,000[1]
Engineer Salary (1 mo. @ $53K/yr)	4,400[2]
Technician Salary (2 mo. @ $37K/yr)	6,200[2]
25 Tests (@ $650/test)[1]	16,250
	43,850

HDV: ($/family)

Vehicle Acquisition	21,300[2]
Engineer Salary (1 mo. @ $53K/yr)	4,400[2]
Technician Salary (2 mo. @ $37K/yr)	6,200[2]
25 Tests (@ $2200/test)[3]	55,000
	86,900

	LDV	LDT	HDV
Cost/Family	$43,850	$43,850	$86,900
Number of Families	137[4]	81[4]	11[3]
Total Cost	$6,007,000	$3,552,000	$955,900
W/ 2 yrs int.(@ 10%)	$7,269,000	$4,298,000	$1,157,000
Amort. (5 yrs @ 10%)	$1,918,000/yr	$1,134,000/yr	$305,100/yr
Projected 1989 Sales	11,000,000[5]	3,640,000[5]	386,000[3]
RD&T Cost/Vehicle ($)	0.17	0.31	0.79

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[1] Inflation-adjusted values from EPA memo, "Light-Duty Vehicle Certification Cost," from Daniel P. Hardin, March 13, 1975. [Reference 15 of Chapter 4.]

[2] Estimated.

[3] "Regulatory Impact Analysis, Oxides of Nitrogen Pollutant Specific Study and Summary and Analysis of Comments," EPA, March 1985. [Reference 17 of Chapter 4.]

[4] EPA's "Control of Air Pollution from New Motor Vehicles and New Motor Vehicle Engines; Federal Certification Test Results for 1984 Model Year."

[5] Based on DRI "trendlong" projections from the Fall 1984 Long-Term Review, Data Resources Inc., 1984.

fuels are assumed to equal the RD&T cost for 9.0 RVP fuel. A summary of the RD&T costs for the different certification fuels are listed in Table 4-5 through 4-7.

Certification Costs

Table 4-A-13 contains a summary of the certification costs associated with a new certification fuel for LDVs and LDTs. The costs per vehicle tested are summarized for both emissions data and durability vehicles. The total costs are based on the number of LDVs and LDTs certified in 1984. However, only those engine families which are carried over from the previous year are relevant, since those which are recertified anew would experience certification costs with or without a new certification fuel. Carryover is estimated to be 90 percent; therefore, the total cost was reduced to 90 percent of its original value. The reduced total was adjusted for 1 year of interest at 10 percent, and then amortized for five years. This amount was then used to determine the cost per vehicle based upon 1989 sales projections. The certification cost for LDVs and LDTs is therefore estimated to be $.71 and $.89, respectively.

Heavy-Duty vehicles have a wider range of vehicle sizes and applications than LDVs/LDTs, thereby making the certification cost more complicated to estimate. Therefore, the EPA has broken the certification cost into exhaust emission and evaporative emission components. Exhaust emission certification would be necessary due to the new requirement that the canister be connected to the engine during testing, and is estimated to be $200,000 per family.[17] This estimate includes both durability assessment and the use of three emission data engines per family. In 1986, HDV manufacturers certified eight families using 23 emission data engines. Total exhaust emission certification costs including durability assessment are therefore estimated to be $1.6 million dollars.

Evaporative emission certification would be necessary due to the proposed test procedure changes. This is estimated to be $31,000 per family ($620 per test * 50 tests per family).[18] In 1986, HDV manufacturers certified 23 family/system combinations. Using these figures, total evaporative emission certification costs are estimated to be $713,000.

Table 4-A-14 shows a summary of these HDV certification costs. Still assuming a one year opportunity cost at 10 percent interest and amortizing the result at 10 percent, the yearly fleet cost will be $671,200. Using a projected sale of 386,000 heavy-duty gasoline vehicles in 1989 [18], the average certification cost is $1.74 per vehicle.

Table 4-A-13

LDV/LDT Certification Cost Summary (1986 Dollars)

Emission Data Vehicle Costs:* ($/Vehicle Tested)

Vehicle Acquisition	17,000
Mileage and Maintenance (@ $2.77/mile, 4000 miles)	11,060
Testing Cost (2 Tests/Vehicle, $650/test)	1,300
	29,360

Durability Vehicle Costs:* ($/Vehicle Tested)

Vehicle Acquisition	17,000
Mileage and Maintenance (@ $3.29/mile, 50,000 miles)	164,500
Testing Cost (13 Tests/Vehicle, $650/test)	8,450
	189,950

Total Vehicles Tested and Costs: ($)

	LDV	LDT
Emission Data (307 LDV, 133 LDT)**	9,013,520	3,904,880
Durability (109 LDV, 45 LDT)**	20,704,550	8,547,750
Total Cost	29,718,070	12,452,630
90% Carryover	26,746,000	11,207,000
W/ 1 yr of interest (@ 10%)	29,421,000	12,328,000
Amortization (5 yrs. @ 10%)	7,761,000	3,252,000
1989 Sales***	11,000,000	3,640,000
Certification Cost/Vehicle ($)	0.71	0.89

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* Inflation-adjusted values from EPA memo, "Light Duty Vehicle Certification Cost," from Daniel P. Hardin, March 13, 1975. [Reference 15 of Chapter 4.]

** EPA's "Control of Air Pollution from New Motor Vehicles and New Motor Vehicle Engines; Federal Certification Test Results for 1984 Model Year."

*** Based on DRI "trendlong" projections from the Fall 1984 Long-Term Review, Data Resources Inc., 1984.

Table 4-A-14

HDV Certification Cost Summary (1986 Dollars)*

Category	Cost ($)
Exhaust Emission Component* ($200,000/family)(8 exhaust families)	1,600,000
Evaporative Emission Component** ($620/test)(50 test/family)(23 evap families)	713,000
Total Cost	2,313,000
W/ 1 yr of interest (@ 10%)	2,544,000
Amortization (5 years @ 10%)	671,200

Projected 1989 sales** = 386,000

Ave. vehicle cost = $671,200/386,000 = $1.74

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* "Regulatory Impact Analysis, Oxides of Nitrogen Pollutant Specific Study and Summary and Analysis of Comments," EPA March 1985. [Reference 17 of Chapter 4.]

** Values from EPA report, "Feasibility, Cost and Cost Effectiveness of Onboard Vapor Control for Heavy-Duty Gasoline Vehicles".

Chapter 5

Technological Feasibility and Cost of In-Use Gasoline Volatility Control

As described in previous Chapters, one of the two possible methods of eliminating the current evaporative emission excess is to control the volatility of commercial gasoline. Estimates of refinery costs and fuel economy benefits of reducing in-use gasoline volatility are presented in this chapter. As described in Chapter 2, the two fuel parameters most relevant to evaporative emissions are RVP and $\%_{160}$. In-use control of both of these parameters is being considered. However, the great majority of the refinery modeling has focused on the control of RVP, as the effect of this parameter on evaporative emissions is most well known.

This chapter begins with a general discussion of gasoline volatility and the types of HC compounds which most affect it (Section I). The next section (Section II) presents a general description of the main sources of information for the cost of in-use gasoline RVP control and $\%_{160}$ control, two studies conducted by Bonner and Moore Management Science for EPA.[1,2] These studies use Bonner and Moore's proprietary Refinery and Petrochemical Modeling System (RPMS), which is a linear programming (LP) computer model. Section III presents the results of the Bonner and Moore studies, primarily the refinery cost of reducing gasoline RVP one to two psi below ASTM limits under various situations, but also includes the cost of reducing $\%_{160}$ to 25 or 30 percent. This section also includes a discussion of revisions that were made to the costs in light of comments received from external review of the reports. Section IV examines the effect of RVP control (and the likely butane excess generated by it) on the wider butane market. Section V examines the effect of RVP control on the energy content of gasoline and estimates the resultant effect on vehicular fuel economy as well as the additional economic benefit of recovering or preventing evaporative emissions (via both fuel- and vehicle-related controls). Section VI discusses how control of fuel volatility affects the driveability of vehicles. Section VII examines the cost of enforcing in-use control regulations.

It should be noted that the refinery costs used in this Regulatory Impact Analysis are a revised edition of those used in EPA's November 1985 study of gasoline volatility. EPA has contracted Bonner and Moore to do additional modeling to ensure that the adjustments made here fully reflect the complexities of U.S. refineries. When completed, the report will be placed in public docket A-85-21 at EPA Headquarters for review.

I. Refinery Control of Gasoline Volatility

Oil refineries currently refine crude oil to supply several petroleum products, one of which is gasoline for motor vehicle consumption. The volatility of the gasoline produced depends on the properties of the crude oil and the natural gas liquids (NGLs), which include butanes and natural gasoline, used in the refining process and on the actual refining processes themselves. There are ASTM specifications for gasoline volatility characteristics which serve as guidelines for the refineries to follow. These ASTM gasoline volatility specifications and in-use volatility trends were already described in Chapter 2, Section II.

As already mentioned, RVP and $\%_{160}$ are the two most important gasoline volatility properties affecting evaporative HC emissions. The major HC compounds contributing to high RVP are n-butane and iso-butane, although n-pentane and iso-pentane also affect RVP. The RVP blending values for these parafins are discussed in Section II of Chapter 2. Generally, the easiest way to reduce gasoline RVP is to reduce the blending of straight butane into gasoline. The next easiest approach is to remove butane presently contained in other gasoline stocks. This requires modification of existing separation facilities and/or the installation of new facilities to remove contained butanes. In addition, butane can be converted, via processes such as alkylation, in higher boiling compounds. As a further step, extreme RVP limits could require removal of some C_5 components which, in most cases, would require new separation facilities. The approach that is actually used depends on the economics involved, which are complex and highly interactive.

Both butanes and pentanes strongly affect $\%_{160}$, but so do many other gasoline components, and the specific relationship between each of these components and $\%_{160}$ is beyond the scope of this study. Suffice it to say that the more short-chain hydrocarbons (with four to five carbon atoms) in gasoline, the higher the RVP and $\%_{160}$.

Butane has a high-octane quality. Thus, RVP control which reduced the use of butane would also require additional refinery processing to compensate for the octane quality which the butane would otherwise provide.

The use of alcohols in gasoline complicates matters, since both methanol and ethanol affect RVP as well as other volatility parameters and octane. Adding 5%/2.5% methanol/TBA to 11.0-psi RVP gasoline increases RVP by 2.2 psi. Adding 10 percent ethanol to gasoline increases RVP up to 1.0 psi. The RVP blending values of methanol and ethanol were discussed in Section II of Chapter 2. Thus, their addition to gasoline must be accompanied by an even greater reduction in butane/pentane content if RVP is to be held constant, though the alcohols' high-octane more than compensates for that of the lost butane in this case.

II. The Bonner and Moore Studies

Bonner and Moore Management Science conducted two studies on the refinery cost impact of vapor pressure control under a number of subcontracts with Southwest Research Institute (SwRI) and Jack Faucett Associates (JFA) as contracted by the Environmental Protection Agency. The results of the studies are contained in fully documented final reports by Bonner and Moore entitled Estimated Refinery Cost Impact of Reduced Gasoline Vapor Pressure dated July 10, 1985 and a supplemental report dated February 26, 1986.[1,2] The general methodology and major assumptions of Bonner and Moore's study are presented below. The results of the study are presented in Sections III. The reader is referred to the Bonner and Moore report for more specific details of the refinery cost study. No attempt is made here to explain the B&M study in detail because of its complexity and the availability of the final report, which is an independent document that fully details the study and results. Results of additional studies are also discussed in the following sections. These include an EPA study performed by Sobotka and Company entitled Cost and Feasibility of Gasoline Volatility Reductions, and a study by the Motor Vehicle Manufacturers Association, performed by Turner, Mason and Company, entitled Refining Cost For Reducing Gasoline Vapor Pressure.[3,4]

A. Bonner & Moore's Refinery and Petrochemical Modeling System

EPA contracted Bonner and Moore to use their proprietary linearly programming (LP) computer model, designated the Refinery and Petrochemical Modeling System (RPMS), to estimate the refinery costs of reducing RVP and $\%_{160}$. One and two-psi RVP reductions below the maximum specified ASTM(D439) RVP and 5 and 10 percent reductions in maximum allowed $\%_{160}$ (from the 35 percent allowed in the base case) were analyzed for each of three geographic gasoline-refinery regions referred to as Petroleum Administration for Defense Districts (PADDS I, II and III). It was assumed that the other two districts, PADDs IV and V, could be approximated by the average of PADDs II and III.

The national average costs for RVP reduction were estimated by consumption weighting the PADD-specific costs obtained from the RPMS. The costs of controlling the volatility of both alcohol-free gasoline and methanol and ethanol blends were examined. Volatility controls were applied uniformly to all three grades of gasoline; unleaded regular, unleaded premium, and leaded regular. The volume fractions of national gasoline production contributed by each of the grades were 65 percent unleaded regular, 18 percent unleaded premium, and 17 percent leaded regular. Leaded gasoline is allowed to contain only 0.1 gram per leaded gallon of lead, so the effects of EPA's lead phasedown program are fully factored in.

There are also some additional assumptions that had to be made in modeling the alcohol-fuel blends. First, gasoline production was set at the same level used in the alcohol-free cases. No fuel economy changes that might apply to alcohol-containing fuels were taken into account. Furthermore, 100 percent of each grade of gasoline, unleaded premium, unleaded regular and leaded regular, was assumed to contain the specified concentration of alcohol. While this is not realistic, it was the most convenient way to include alcohols in the RPMS and the results appear to be reasonable. (As will be discussed below, this same approach was used to model ethanol blends and the results were clearly unreasonable). Also, a lower RVP case study of three psi below the baseline vapor pressure was evaluated for the methanol blend because of the possibility that commingling of the blend with alcohol-free gasoline would increase RVP beyond that of either fuel due to the azeotropic behavior of alcohol and hydrocarbon mixtures (discussed further in Section II of Chapter 2). The 1-psi further reduction in vapor pressure would tend to partially offset any increase in vapor pressure due to such commingling effects, resulting in evaporative emissions equal to those for alcohol-free fuels.

The estimated costs in all cases for each PADD were developed by the RPMS using a single "super refinery" to represent all of the refining capabilities of that PADD (i.e., the average refinery). This super refinery was required to produce all of the gasoline projected to be produced by all of the individual refineries in that PADD in the timeframe of the study, which was 1990. Individual refineries would be expected to experience costs both above and below that estimated by the RPMS, but on average, the actual costs should be close to that projected by the model. The complexities involved with modeling individual refineries make such an approach economically infeasible and make the use of a single refinery a necessary limitation of this study.

The gasoline costs estimated by the RPMS are, by design, incremental in nature and do not attempt to represent the full cost of refining gasoline. This avoids a number of complex issues associated with valuing capital equipment already in place. As the desired output is the effect of RVP on refining costs, a difference between an uncontrolled and controlled scenario, this is fully satisfactory for this study.

To accomplish this, a base 1990 case is run to determine optimal process requirements and refinery costs associated with producing the 1990 product slate, considering process capacities known to be available in 1984, and, thus, not requiring capital investment. The controlled case is run in an analogous fashion (i.e., a fresh optimization from 1984 capacities), only with a lower RVP or $\%_{160}$ product. Conceptually, this approach assumes that investment occurring between now and 1990 in the uncontrolled case can be redirected toward more productive use, if economically desirable, in the controlled case. This may or may not be the case, depending on the timing of any volatility controls. Information from the past model runs however, show that very little of the investment occurring in the base case does not also occur in the controlled case. Thus, little redirection of 1984-1990 investment appears to be occurring and the effect of allowing this in the modeling runs appears to be small.

For those readers investigating such details, it should be noted that the RPMS runs tend to project sizable capital investments between 1984 and 1990 for the base cases even though the refinery industry as a whole is expected to invest little for gasoline capacity aside from environmental control (i.e., lead phasedown).[2] This occurs because the current capacity of many peripheral processes (e.g., cooling towers) is not known and was presumed to be zero in 1984 for modeling purposes. Thus, the required 1990 base capacity for these processes is considered to be entirely incremental, though in all likelihood, the vast majority of it is currently in place. These sizable capital investments have no direct effect on the estimated RVP control costs, nor the estimated capital investment required for RVP control, since these are incremental costs involving the subtraction of base case costs from the controlled case costs, both of which contain these costs. It simply means that the capital investment shown for either the base or controlled cases cannot be used to estimate the total capital investment required by the refining industry between 1984 and 1990. However, as the current capacities of some of these peripheral processes may be in excess of that needed in 1990, the model may be overestimating the additional capacity needed for RVP control. The degree to which this may be occurring is unknown and is not easily estimated.

The original RPMS runs also assume that all capital investment is amortized over year-round production. This is appropriate in the base case, since most of this equipment is of the kind that is used year round. However, equipment purchased expressly for RVP control might only be used during the specified five-month RVP control season and are thus only amortized over five months. The supplemental report by Bonner and Moore showed the facilities purchased to control RVP had little value in the non-control period, and should be amortized only over the control season. Amortizing equipment only over 5 months raises the refining costs and this increase will be discussed in the results section.

A no-investment scenario was modeled primarily to simulate the situation where the leadtime granted to refiners prior to RVP controls was insufficient to design and build new capital, but it applies as well to the extreme situation in which the model itself avoids all incremental capital investment because capital investment associated with RVP control has no value outside of the RVP control period. While in theory the cases were to be strictly no new investment, this stipulation had to be relaxed in practice, again due to the unknown current capacities of many peripheral processes. It did not seem reasonable to limit such capacities to those required in the base case, because historic gasoline production has been much higher than projected 1990 levels and much excess capacity could exist. At the same time, the degree of this excess is unknown. Thus, the no-investment costs may be underestimated, since the benefit of some capital investment may be included. The extent to which this is true is not known and is not easily estimated. Thus, these costs represent the best estimates available under such conditions.

The degree of RVP control that can be achieved in a no-investment scenario can theoretically be determined by the modelling results. In the Bonner and Moore modelling, however, this is not the case due to the lack of knowledge of the capacities of peripheral processes as discussed above. This issue of lead-time, how low RVP can be reduced without capital investment, was examined by Sobotka and Company.[3] The results of the analysis will be discussed in the next section.

Another important aspect of modeling refinery RVP control is the treatment of natural gas liquid (primarily butane) supply and demand. Currently the butane market varies dramatically between summer and winter. With gasoline RVP levels 2 psi higher in the winter (corresponding to a butane composition increase of 4 percent by volume), butane supplies tend to be short and prices high. In the summer, the opposite is true. With RVP control, even more butane will be available in the summer and prices could decrease further. This potential price decrease is dependent on the entire butane/petrochemical market and not just on petroleum refinery operations. Thus, a model such as RPMS, which only models petroleum refining, cannot project the price drop. In fact, the price of butane must be input to the model.* However, two types of situations were modeled using RPMS to simulate the effect of the potential price drop.

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* Current modelling efforts will model petroleum refining and ethylene manufacture. A separate analysis will determine butane market impacts by the volumes of butane not consumed by these sectors.

The first situation assumed that butane could be purchased or not purchased at its current price, which varies with PADD, depending on its economic usefulness. This situation is referred to as the "open" NGL purchase scenario. Butane availability was limited to that purchased by refineries in recent times. The second situation forced the refinery to purchase all of the available butane at the current summer price. This situation is referred to as the "fixed" NGL purchase scenario. The first situation was intended to place a lower limit on RVP control costs by allowing refineries to sell any excess butane generated by RVP control at current market prices. In reality, lower butane prices would probably occur, thereby reducing the profitability of doing this and also increasing the cost of RVP control. The second situation was designed to place an upper limit on RVP control costs by requiring the refinery segment of the butane market to use all of the excess butane at current market prices. In reality, prices would drop and other segments at the market would utilize at least part of the butane excess and result in lower RVP control costs. In addition, analysis of the impact of RVP control on the entire butane market was performed. Its results are described in Section IV below.

Until more detailed information is available, the midpoint between costs under the "fixed" and "open" NGL purchase scenarios will be used for the cost of RVP control. Further discussion on the decision to choose the midpoint between these two scenarios is presented in Section IV below.

The final aspect of the RPMS deserving discussion here is the way the model simulates ASTM gasoline specifications. RVP levels for the uncontrolled RVP base case were set at maximum ASTM D-439 RVP specifications. PADD average maximum RVPs were estimated by volumetrically weighting the RVPs of all the gasoline produced by refineries in a particular PADD. National average maximum RVPs were estimated by volumetrically weighting the PADD-specific RVPs by the volume of gasoline produced in each PADD. RVP of PADDs 4 and 5 was assumed to be the average of the RVPs for PADDs 2 and 3. The PADD-specific RVPs and national RVPs are presented in Table 5-1. The volumetric production weighting factors are also presented at the bottom of Table 5-2. Current (1986) national average gasoline RVP, as determined from the MVMA fuels survey, is 11.06 psi, which is near the maximum ASTM RVP specification of 11.27 psi. It is assumed that, by 1990, the national average RVP will equal the maximum ASTM RVP specification. This was discussed in detail Section II of in Chapter 2.

Besides RVP, ASTM addresses fuel volatility by specifying minimum and maximum temperatures at which specified fractions of the fuel are evaporated via distillation (i.e., T_{10} and T_{50}) as discussed in Section IV of Chapter 2. Such

Table 5-1

National and PADD-Specific RVPs and $\%_{160}$s Resulting from Bonner & Moore RPMS Cases

PADD	NGL Purchase Scenario	Level of RVP Control					
		Baseline (B)		1 psi Reduction		2 psi Reduction	
		RVP	$\%_{158}$	RVP	$\%_{158}$	RVP	$\%_{158}$
I	Open	11.5	34.978	10.5	33.7	9.5	32.1
I	Fixed	11.5	34.978	10.5*	33.778*	9.5	32.0
II	Open	11.46	33.028	10.46	32.487	9.46	31.808
II	Fixed	11.46	35.0	10.46	33.284	9.46	30.739
III	Open	11.12	33.144	10.12	30.753	9.12	28.325
III	Fixed	11.12	33.144	10.12*	31.184*	9.12	28.28
Nat. Avg	Open	11.27	33.27	10.27	31.59	9.27	29.82
Nat. Avg	Fixed	11.27	33.92	10.27*	32.11*	9.27	29.42

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* Found by interpolation between (B) and (B-2) cases for the II_F condition
RVP = midpoint between baseline and the 2-psi control case
$\%_{158}$ = (baseline) - 0.403 [(baseline) - (baseline-2)]

Table 5-2

Cost of RVP Control
($ per Barrel of Gasoline)

RVP Reduction, psi	PADD 1	PADD 2	PADD 3	PADD 4 + 5 (ex. CA)[1]	Total U. S. (ex. CA)[2]
Alcohol-Free Gasoline					
With Investment, Open Butane Purchases					
1	0.184	0.365	0.211	0.288	0.259
2	0.547	0.748	0.501	0.625	0.587
With Investment, Fixed Butane Purchases					
1	0.189[3]	0.396	0.212[3]	0.304	0.271
2	0.561	0.857	0.504	0.681	0.626
With Investment, Average of Fixed and Open Butane Purchases					
1	0.186	0.380	0.212	0.296	0.265
2	0.554	0.802	0.502	0.653	0.606
No Investment, Fixed Butane Purchases					
1	0.214[4]	0.501[4]	0.300[4]	0.401	0.358
2	0.641	1.084	0.713	0.899	0.826
No Investment, Estimated Average of Fixed and Open Butane Purchase					
1	0.211	0.480	0.300	0.390	0.350[5]
2	0.633[5]	1.014[5]	0.710[5]	0.862[5]	0.800[5]
2.5% MeOH + 2.5% TBA Blend, with Investment, Open Butane Purchases					
1	0.369[6]	0.407[6]	0.314	0.360	0.35
2	0.815	0.898	0.692	0.795	0.77
3	1.370[7]	1.509[7]	1.163	1.336	1.29
5.0% MeOH + 2.5% TBA Blend, with Investment, Open Butane Purchases					
1	0.195[8]	0.387[8]	0.224[8]	0.298	0.27
2	0.581[8]	0.794[8]	0.532	0.676	0.62
PADD-Specific Fraction of Total Gasoline Volume (%)					
	8.2	23.3	48.0	20.5	100.00

Footnotes on following page.

Table 5-2 (cont'd)

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1 Estimated as average of cost for PADDs 2 and 3.

2 Total U.S. (ex. CA) costs were estimated by volumetrically weighting of PADD-specific costs for PADDs 1, 2, 3, and 4 and 5 (excluding California) using PADD-specific gasoline production.

3 Actual case not run, cost estimated from open butane purchase for 1-psi RVP reduction using the percentage increase for 2-psia reduction costs between open and fixed NGL purchases.

4 Actual case not run, cost estimated from fixed butane purchase costs with investment for 1-psi RVP reduction using the percentage increase between 2-psia reduction costs with and without investment.

5 These costs were estimated from the No-Investment costs for fixed butane purchases presented in the previous row using the ratio of midpoint (open-fixed)/2 vs. fixed butane purchases costs for the cases with investment.

6 Actual case not run, cost estimated by applying ratio of 1-psi reduction cost to 2-psi reduction cost for PADD 3 control to the 2-psi reduction cost for PADD in question.

7 Actual case not run, cost estimated by applying ratio of 3-psi reduction cost to 2-psi reduction cost for PADD 3 control to the 2-psi reduction cost for PADD in question.

8 Actual case not run, cost estimated using the ratio of corresponding costs from open butane purchase cases for alcohol-free gasoline with investment applied to PADD 3 cost for 5%/2.5% MeOH/TBA from B&M.

specifications do not lend themselves to linear programming since temperatures at which certain fuel volumes are evaporated cannot be easily manipulated when two fuel streams are merged. It is much easier to work in the reverse mode, the percent fuel evaporated at specific temperatures (i.e., $\%_{160}$), since these can be volumetrically averaged when two streams are blended together. This is the mode in which the RPMS works. It is possible to convert from one mode to the other, but only approximately. Thus, at the present time, it is not clear precisely how the RPMS limits (other than RVP) approximate those of ASTM. However, the RPMS requirements specified by B&M for maximum percent of gasoline evaporated at a given temperature appear to be within the ASTM requirements specifying minimum and maximum temperatures corresponding to a given percent of gasoline evaporated. ASTM D-439 requirements for minimum and maximum temperatures corresponding to a given percent of gasoline evaporated are not tight specifications, and current fuels are not being restricted by these requirements.

The point of major concern on the gasoline distillation curve is the $\%_{160}$, as discussed in Section II of Chapter 2. Bonner and Moore limited the maximum $\%_{160}$ to 35 percent for the RPMS cases in their original study. This resulted in the values of $\%_{160}$ presented in Table 5-1, for the specific PADDs and for the national on a whole. Current (1986) national average gasoline volatility properties are 11.06-psi RVP and 32.6 $\%_{160}$. These values are those for volumetrically weighting all gasoline grades (65 percent unleaded regular, 18 percent unleaded premium, and 17 percent leaded regular), but are also the same as those for unleaded regular gasoline as presented in Table 2-6 of Chapter 2. The average $\%_{160}$ of current gasolines is approaching 35 percent, indicating that the B&M restriction of 35 $\%_{160}$ is not too lax. Therefore, the B&M costs for RVP control with $\%_{160}$ restricted to 35 percent appear reasonable from this point of view.

B&M modeled some additional cases to evaluate the cost of further controlling $\%_{160}$, both independently and in addition to RVP control. The cases evaluated and the results of running these cases with the RPMS are presented in the following section.

III. Refinery Costs of Volatility Control

A. RVP Control

The projected costs of 1- and 2-psi RVP reductions below the maximum ASTM-specified RVP for various gasoline types and other scenarios are shown in Table 5-2. Before discussing the results of Table 5-2, it should be noted that the $\%_{160}$ of these fuels are indirectly reduced through this RVP control, because removing compounds which contribute to high RVP also lowers $\%_{160}$, to a certain extent. The reductions in $\%_{160}$ associated with these 1- and 2-psi RVP reductions for the "open" NGL purchase scenario are 1.7 percent and 3.5 percent, respectively, as indicated by the national average levels for $\%_{160}$ presented in Table 5-1. The $\%_{160}$ is reduced 1.8 and 4.5 percent for the corresponding "fixed" NGL purchase scenario.

The cost of controlling the RVP of alcohol-free gasoline is of primary concern, since it represents nearly 93 percent of all gasoline sold in the U.S. (with gasohol making up the other 7 percent of the nations gasoline sales.) As can be seen in Table 5-2, the nationwide-average cost of reducing RVP by 1 psi is 0.62-0.95 cents per gallon ($0.259-0.358 per barrel), while the cost of a 2-psi reduction is greater than two times that, or 1.40-1.97 cents per gallon ($0.587-0.826 per barrel), depending on how capital investment and the butane market are treated. These values are the results of the modeling being performed with a crude oil price of approximately $30 per barrel.

The least expensive RVP control scenarios are those in which the refineries have the ability to invest in capital equipment to optimize their refinery processes. This situation occurs when the controls are to be in place long enough to justify the capital investment and after refiners have had sufficient time to design and implement new equipment. This definitely applies to the long-term control scenario (i.e., 2010) and may apply to short-term controls if the above two conditions are met.

In addition, two extreme scenarios were evaluated with capital investment permitted, one with "open" NGL purchases and one with "fixed" NGL purchases, as described earlier. RVP control for the "open" NGL purchase scenario was slightly less expensive than for the "fixed" case ($0.587 vs. $0.626 per barrel for a 2-psi RVP reduction, respectively).

For the no investment situation, only fixed NGL cases were modeled. Open NGL costs were estimated from the runs "with investment" to determine the best estimate midpoint "no-investment" cost, as shown in Table 5-2. These "no investment" costs simulate short-term control if refineries are not given sufficient time to invest in capital prior to control or if the period of control is too short to justify capital investment (generally thought to be 2-4 years). Although the costs for controlling RVP in a no-investment scenario are shown for both a 1-psi and 2-psi reduction, recent analysis found only a 1-psi reduction is feasible in the short run.[3] In the EPA study performed by Sobotka and Company, a one-psi reduction in RVP was found to be the upper limit of volatility reductions due to current gasoline production capabilities in the U.S. Lead phasedown regulations and higher gasoline demand due too low crude oil prices prohibit the refining industry from reducing RVP by more than 1-psi without further capital investment. The 1-psi reduction was found to be feasible for all the ASTM classes in the short term.

The cost of controlling the RVP of alcohol-blends follows the same general PADD-to-PADD trend as that for alcohol-free gasoline. Overall, the cost of vapor pressure control is greater for gasoline containing the 2.5/2.5 percent methanol/TBA blend, than for alcohol-free gasoline. The cost of a 3-psi reduction for PADD 3 (the only PADD evaluated) is increased 68 percent over that of just a 2-psi reduction. This increase may differ slightly between PADDs, but was assumed to be constant in Table 5-2.

The cost of reducing RVP for the 5.0/2.5 percent methanol/TBA blend, in contrast, is less than that for the 2.5/2.5 percent methanol/TBA blend and is 6-7 percent greater than that for alcohol-free gasoline, on average. Bonner and Moore credits the smaller cost to the non-linear vapor pressure blending behavior of the additional methanol. The additional 2.5 percent of methanol incurs a small additional vapor pressure penalty but contributes a larger octane benefit. As this is expected to be more popular than the 2.5/2.5 percent methanol/TBA blend in the future, and its RVP control costs are so close to that for alcohol-free gasoline, only the cost for alcohol-free gasoline will be used hereafter.

As indicated above, attempts were made to model 10 percent ethanol blends, in the same manner as methanol blends. However, in all cases, the base (uncontrolled) RVP was already very near or below the 2-psi reduction level. This was an artificial result of restricting $\%_{160}$ to 35 percent. This is unrealistic for current ethanol blends, as ethanol dramatically affects $\%_{160}$ and current levels of $\%_{160}$ for ethanol blends at 11.5-psi RVP are around 42 percent. Thus, the forced lowering of $\%_{160}$ likely forced most of the butane out of the fuel and lowered RVP dramatically prior to control. This situation is being corrected in additional modeling currently being conducted by B&M. Results are not available yet, but will be incorporated in the study of controlling evaporative emissions as soon as the RPMS case studies are complete.

Thus, little can presently be said based on actual refinery modelling about the cost of controlling the RVP of ethanol blends. Qualitatively, ethanol has a smaller RVP effect and greater octane effect than methanol/TBA mixture. Thus, one would expect its presence to impact RVP control costs less than the methanol/TBA mixture when $\%_{160}$ is not controlled. Since the methanol/TBA blend increased cost by approximately 7 percent over control cost for alcohol-free gasoline, any additional cost to control ethanol blends is assumed to be negligible. This holds for the case discussed in

Chapter 1 where alcohol fuels are given a one-psi allowance over alcohol-free gasoline. If alcohol blends are required to meet the same RVP specifications of alcohol-free gasoline, then the control cost is equal to the cost of controlling the RVP of alcohol-free gasoline plus the cost to control the next one-psi increment. This results from the fact that ethanol will contribute one-psi RVP to the base gasoline. This additional cost to control RVP of ethanol blends will be quantified below. The impact on the ethanol blending industry of controlling the quality of the finished blend (i.e., eliminating splash blending and requiring coordinated blending) will be discussed in Chapter 7.

The costs in Table 5-2 were used in EPA's 1985 study of gasoline volatility and hence have been extensively reviewed. Modeling efforts are currently underway to fully address the comments made to the original study. The comments, which will have the greatest impact on the costs, can be incorporated into the estimates of Table 5-2. The details of the revisions are described below.

The most important revision to make to the cost is to reflect the drop in crude oil prices which occurred after the study was published. The 1985 Bonner and Moore costs are based on crude oil prices of approximately $30 per barrel. The revised cost estimates will be developed at three crude oil price scenarios, $15, $20, and $25 per barrel with $20 per barrel being the base case assumption. The revisions to the Bonner and Moore costs can be made by modifying the costs of the swing crude purchases in each PADD. The difference in the assumed crude oil price and the actual price in the model was determined and then multiplied by the swing crude purchases in the RVP control cases. This savings in crude purchases was subtracted from the total cost in each case modeled by Bonner and Moore. For the first psi reduction in RVP, the nationwide costs for the $25, $20, and $15 per barrel cases were 16, 32, and 46 percent less than the original costs, respectively.

This methodology for changing costs due to crude oil prices is considered to be the conservative approach. If the computer model was reoptimized for the lower crude cost cases, the model would opt for raw material purchases over investment to a greater extent and possibly further reduce RVP control costs. It is likely, however, that as crude cost decreases consumer demand would increase and the refinery would lose some flexibility. These issues are currently being evaluated by Bonner and Moore and will be incorporated into the final RIA when completed.

The second revision is an adjustment for the lower purchase price of butane in the control cases. In the Bonner and Moore study the butane purchase price was held constant at approximately $23.00 per barrel. As will be discussed in the next section, as RVP is controlled and butane backed out of gasoline, the price of butane will drop until it reaches a value at which it is competitive as a petrochemical feedstock. This price was calculated at approximately $20.00 per barrel. This lower butane price will affect the price of all butane on the market (not only those backed out of gasoline) since, as the Gas Proccessors Association noted in their comments on EPA's gasoline volatility study, a two-tier price structure for butane could not exist.[5] This lower butane price in the control cases is a savings to the refining sector over the higher price in the control cases of the Bonner and Moore study.

The above-mentioned figures were derived for a $30 per barrel crude oil situation. The price of butane and hence the increment was assumed to change proportionately with crude oil price. These savings were applied to each barrel of butane purchased in the control cases. The effect of the lower value of butane ranged from no change in the PADD 1 cost to a $0.046 per barrel decrease in cost in PADD 3. The effect of the lower value of butane was only calculated for the open butane purchase scenario, since the fixed scenario represents the case where there is no impact on the NGL industry (i.e., refiners continue to purchase the same amount of butane at the high price).

The original Bonner and Moore costs assumed that all capital investment be amortized over year-round productions. This is appropriate in the base case, since most of this equipment is of the kind that is used year round. However, equipment purchased expressly for RVP control in the control cases will only be used during the specified five-month RVP control season and, thus should only be amortized over five months. The supplemental report by Bonner and Moore showed the facilities purchased to control RVP had little value in the non-control period, and should be amortized only over the control season.[2] The effect of a 3-month period of recovery of control-facilities is an increase in the control costs of 9 percent. For a 5-month control period the cost increase was assumed to be 7 percent. The effect of the crude oil price, the lower value of butane, and the shorter control period on the refinery costs (average of open and fixed) is shown in Table 5-3.

The values of Table 5-3 have been extrapolated to the third psi RVP reduction step using the data availability in Table 5-3. The incremental cost of reducing RVP from the one psi reduction to the second psi reduction was compared to the cost of reducing the RVP by the first psi. For the alcohol-free gasoline, the second increment of control increased over the first increment by an average of 30 percent. It was assumed that the third increment of control would increase by a similar percentage over the second increment. This assumption was confirmed by the results of the

Table 5-3

Revised Cost of RVP Control

($ per Barrel of Gasoline)

RVP Reduction, psi	Crude Oil Price ($/bbl) 30	25	20	15
1	0.278	0.228	0.181 (.232)*	0.137
2	0.636	0.533	0.443	0.354
3	1.101	0.930	0.784	0.636

---

* No investment.

2.5 percent methanol, 2.5 percent TBA case in Table 5-3, the only case in which a 3 psi reduction was investigated. In that case the third increment increased over the second increment by a percentage that was similar to increase of the second increment to the first increment. Therefore, an increase in the second increment of control of 30 percent was applied to the revised cost of Table 5-3 and then added to the second psi control step to determine the cost of control for the third psi. This assumption was also confirmed by the results of a study by the Bonner and Moore which was prepared for the California Resources Board.[6] This study was particularly interesting since it investigated RVP control cost from a baseline of 9.0 psi. The cost results are not as relevant today, since the study was completed in 1983, however, the change in the increment of cost is relevant. The study found the cost of reducing RVP from 8 psi to 7 psi to only be 16 percent greater than the cost of controlling RVP from 9 psi to 8 psi. Additional modeling efforts are investigating the cost to control RVP by 3 psi as well as cost of controlling RVP in California. The results will be incorporated into this analysis when completed.

As discussed above the cost to control ethanol blends is dependent on the control strategy chosen. If blends are given a 1-psi allowance then cost to control the blends will be the same as non-alcohol gasoline. If blends must meet the same RVP specification as non-alcohol gasoline, then the base gasoline must be 1-psi lower in RVP. As indicated in Table 5-3, the extra increment of control on alcohol blends would increase control cost by \$0.18-\$0.34 per barrel, depending on the level of RVP control.

B. Cost of Volatility Control of $\%_{160}$ of In-Use Fuels

In addition to the control of in-use fuel RVP, the mid-range volatility, specifically the $\%_{160}$, has received attention as another possible controllable parameter which can lead to reductions in evaporative emissions. The effect of mid-range volatility on evaporative emissions was presented in Chapter 2. This section is intended to present the refinery costs of controlling the $\%_{160}$ of in-use fuels (gasohol, methanol blends, and straight gasolines). The costs presented in this section will be combined with the evaporative emission reductions from Chapter 2 to predict the cost effectiveness of reducing the $\%_{160}$ of in-use fuels in Chapter 6.

For the original EPA volatility study, Bonner and Moore Management Science, under sub-contract to Southwest Research Institute, used a computer refinery model to determine the cost of gasoline and alcohol blend volatility control.[1,2] Table 5-4 contains the Bonner and Moore results for reducing the $\%_{160}$ point under different fuel scenarios adjusted down by a ratio of 0.74. This adjustment accounts for changes in the

Table 5-4

Refinery Cost of $\%_{160}$ Reduction

Case	RVP (psi)	Change in $\%_{160}$	Change in $\%_{160}$ of Pool Base Gasolines[1]	PADD 2 Cost ($/Barrel in pool)	Nationwide Cost ($/barrel in pool/ $\Delta\%_{160}$ in pool base gasoline)
All alcohol-free gasoline	9.46	30.74-30	30.7-30.0	0.033	0.032
All gasoline containing 5.0/2.5 MeOH/TBA	9.46	35-30	23.6-18.2	0.459	0.061
7% of pool is gasohol (Only gasohol $\%_{160}$ reduced)	11.46	45-35	34.4-33.7	0.017	0.018
7% of pool is gasohol (All fuel $\%_{160}$ reduced)	-	35-25	33.7-23.6	0.559	0.040

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* The $\%_{160}$ blending value used for 10% ethanol in gasoline was 220, for 7.5% MeOH/TBA (2:1) the blending value used was 175.

price of crude oil and other changes in modelling approaches as explained earlier in this chapter which have occurred since the publication of the original Bonner and Moore reports.

In this $\%_{160}$ analysis, the cost of mid-range volatility control is based on the properties of the base gasolines in the entire pool. This approach is taken because the base gasoline is the component of alcohol/gasoline blends which will have to be modified to counter the increased volatility effects of the alcohol. The volatility properties of the alcohol are fixed and cannot be adjusted.

The change in the $\%_{160}$ value of the base gasolines in the entire pool is calculated based on the change in $\%_{160}$ value of the fuels affected and alcohol blending values. The PADD2 costs are worst case results, and a nationwide (excluding California) cost per barrel of gasoline in the pool is calculated by a ratio of the nationwide (excluding California) costs to PADD2 costs determined in the first Bonner and Moore report for RVP control. The numbers used for the ratio are found in Table 5-5 of this report and the average of the fixed and open butane purchase ratios is used.

The final cost determined is the nationwide (excluding California) cost per barrel of gasoline per percent change in the pool $\%_{160}$ value. Figure 5-1 is a plot of the cost per barrel per $\%_{160}$ reduction versus the base $\%_{160}$ value of the pool. It is used to determine the final cost of $\%_{160}$ reduction.

It should be noted that there are two separate estimates of costs over the $\%_{160}$ range of 33.7 to 23.6, one cost based on a scenario in which seven percent of the fuel supply is gasohol, and the other cost based on an alcohol-free fuel scenario. For the gasohol scenario, the change in the $\%_{160}$ of the pool base gasoline was 33.7 to 23.6, but for the alcohol-free scenario, the actual change in the pool base gasoline $\%_{160}$ was only 30.74 to 30.0. The cost of $\%_{160}$ reduction per percent change in the $\%_{160}$ for the alcohol-free scenario is assumed to hold over the range from 33.7 to 23.6 and two lines of different slopes are drawn in Figure 5-1 to represent the data. Over the $\%_{160}$ range from 23.6 to 18.2, two lines of the same slope are drawn, representing the same cost per percent change in pool $\%_{160}$, but starting at different points.

These separate cost curves result in a range of the cost estimate for several $\%_{160}$ reduction fuel scenarios. The final total cost of reducing the $\%_{160}$ value under the various fuel scenarios is listed in Table 5-6 and is based on annual fuel consumption projections from MOBILE3. As previously mentioned, the cost effectiveness of reducing the $\%_{160}$ of in-use fuels will be presented in Chapter 6.

Table 5-5

Cost of RVP Control*
($ per barrel of gasoline)

RVP Reduction (psi)	PADD 1	PADD 2	PADD 3	PADD 4 + 5 (ex. CA)	Total US (ex. CA)
1	0.186	0.380	0.212	0.296	0.265
2	0.554	0.802	0.502	0.653	0.606

---

* These are the costs for alcohol-free gasoline, with time allowed for investment in new equipment, and the averages of fixed and open butane purchases. Taken from Bonner & Moore report, "Estimated Refining Cost Impact of Reduced Gasoline Vapor Pressure."

Figure 5-1

COST OF REDUCING BASE GAS POOL %160 F

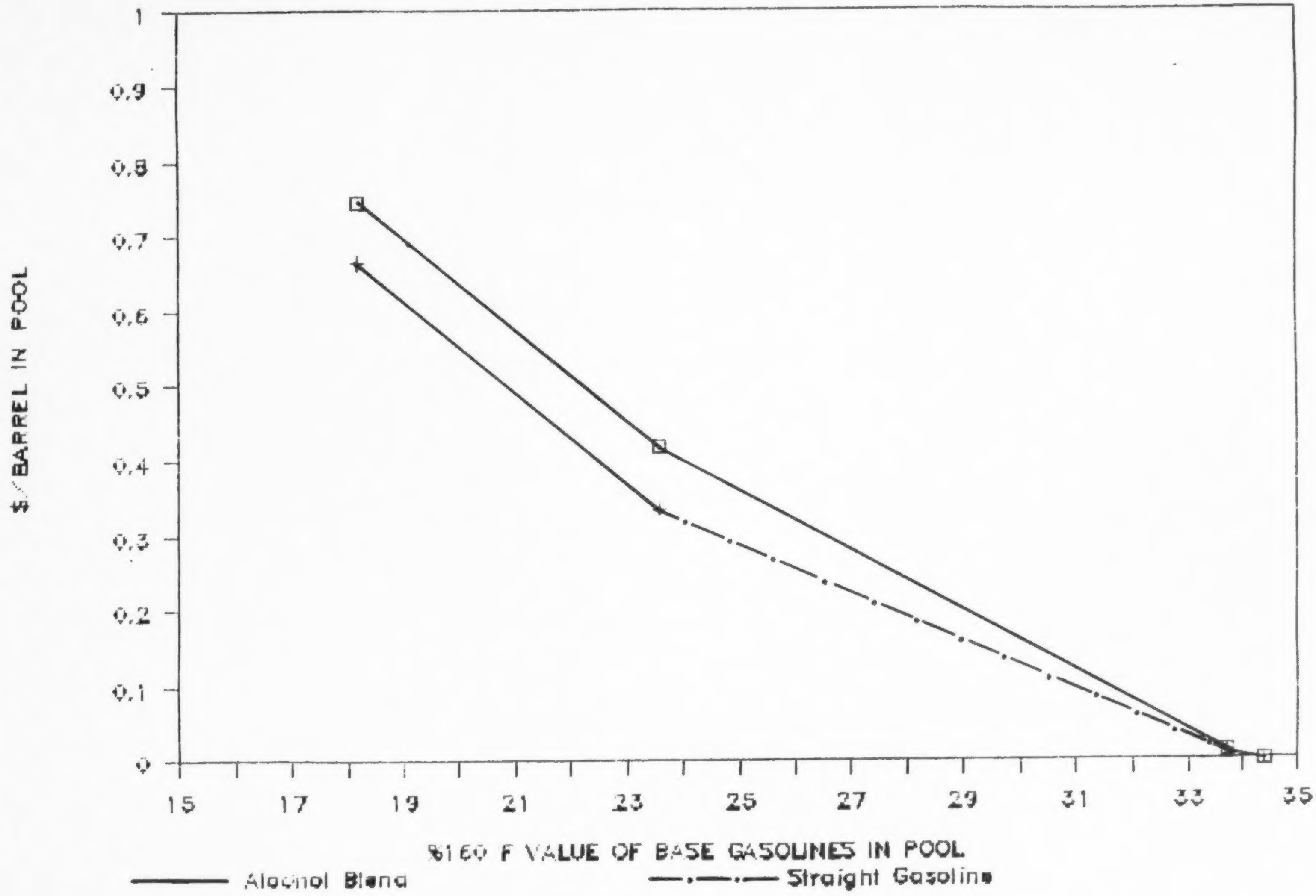

Table 5-6

Cost of Reducing $\%_{160}$ of In-Use Fuels

Fuel	Final $\%_{160}$	Pool $\%_{160}$	Cost per Barrel of Fuel In Pool ($)	Total 1990 Cost[1] (10^6\$/yr)	Total 2010 Cost[2] (10^6\$/yr)
Gasohol	45	34.4	*	*	*
	35	33.7	0.013	23.7	21.2
Methanol	45	35.0	*	*	*
	35	34.6	0.007	13.5	12.1
All Fuels	35	33.3	*	*	*
	30	28.2	0.163-0.204	308.7-387.7	275.7-346.4
	25	23.2	0.333-0.412	634.0-784.1	566.5-700.6

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* Base from which costs, emission reductions, and cost effectiveness results are determined.

[1] Based on MOBILE3 fuel consumption model prediction of gasoline sales of 79.901 x 10^9 gallons in 1990.

[2] Based on MOBILE3 fuel consumption model prediction of gasoline sales of 71.395 x 10^9 gallons in 2010.

IV. Effect of RVP Control on the Butane Market

The major method of RVP control is to remove butane from gasoline, as described in Section II, and to replace the butane with heavier components. The butane that is no longer used in gasoline is made available to the market, including refineries, and this excess supply could and likely will decrease the market price of butane and economically impact suppliers and purchasers. While in aggregate, this economic impact should be zero (i.e., the benefits to purchasers of cheaper butane and/or the products made using butane should equal the cost to suppliers), there may be economic impacts on isolated segments of the butane market. It is likely that most if not all of the NGL industry impact will be a transfer of revenues from one sector of the economy to another. Lost revenues to the NGL industry would largely be made up by increased revenues to current butane users or by reduced cost to consumers of products which involve butane in their manufacture.

The amount of excess butane that will result from a one-psi reduction in RVP was made by the Gas Processors Association (GPA) in their comments on EPA's gasoline volatility study.[5] They assumed that a one-psi reduction in RVP would result in a 2 percent reduction in gasoline production, with virtually all of the reduction being butane. Applying this 2 percent to the 2 billion barrels per year of motor gasoline production, the GPA estimated an excess butane volume of 40 million barrels per year. Over a 5-month control program this would amount to 17 million barrels of excess butane. This is a simplistic approach since it does not recognize any alternative use of butane, either within the refinery or outside the refinery. A more accurate approach would be to examine the results from the Bonner and Moore study. For the open butane purchase scenario, in PADD's 1 and 3, the modelling found the refinery purchased all the butane in the one-psi reduction case that was purchased in the base case. The results of PADD 2 showed 28,531 barrels per day were not purchased in the control case, versus the base case. Extrapolating these results to a nationwide, 5-month control period, the model predicts 5.5 million barrels of excess butane will be generated. For a 2-psi reduction, the model predicts 9.4 million barrels of butane will not be purchased by refiners. These estimates are considered to be conservative since, in the refinery model, the refiners were allowed to purchase butanes only at the high butane price. If excess butanes reached the market and a price decrease was realized, the refiners may be able to utilize the low-priced butane to a greater degree.

Jack Faucett Associates (JFA) was initially contracted to evaluate the effect of reducing the RVP of gasoline on butane prices and usage. The results of their study are presented in a report entitled, "The Butane Industry: An Overview and Analysis of the Effects of Gasoline Volatility Control on Prices and Demand".[7] JFA concluded that excess butane supply from any level of RVP reduction evaluated would be large compared to actual butane demand as a fuel or as a petrochemical feedstock. Thus, they concluded that any significant RVP reduction would result in enough excess butane to cause butane prices to fall to the level of the petrochemical floor price. However, the demand for these other feedstocks is large enough that even extreme reduction of RVP would not result in providing enough additional butane to drive the price below the petrochemical floor price.

The JFA study, dated May 30, 1985, needed to be updated to reflect the current butane market situation, the current crude oil price as well as to address other comments received from EPA's gasoline volatility study. Bonner and Moore will be investigating the butane market impacts and releasing the results along with the results of the updated refinery computer model runs. Bonner and Moore will address the issue of the possible increased value of low price butanes to refiners, alternative uses for butanes, and the total impact not only on butane but for the full range of natural gas liquids. Until more detailed information is available, the average of the fixed and open butane purchase scenarios will be used for the refining cost. The open butane purchase scenario represents the case where all losses to the NGL industry result in increased revenues to other sectors. The fixed scenario represents the other extreme where no transfer of revenues occur. The results of the Bonner and Moore study will be incorporated into the final RIA when completed.

V. Increased Energy Energy Density and Evaporative Emissions Recovery

This section presents an analysis of the effect of reducing the volatility of gasoline on fuel economy. It is hypothesized that, if gasoline volatility is reduced by removing butane from gasoline and replacing it with other fuel components, the heat of combustion of the gasoline will increase. Furthermore, vehicular fuel economy should increase with an increase in fuel heat of combustion. Thus, there should be a fuel economy benefit resulting from reducing the volatility of in-use gasoline. As a result of the analysis, it is estimated that reducing RVP by 0.5 and 3.5 psi will increase fuel economy by from 0.090 to 0.105 and 0.890 to 1.031 percent, respectively, for feedback and non-feedback-equipped vehicles.

The remainder of this section explains how these estimated increases in fuel economy were determined. It is divided into three parts: 1) the relationship between gasoline volatility and fuel heat of combustion, 2) the relationship between the heat of combustion and fuel economy, 3) the overall relationship between gasoline volatility and fuel economy, and 4) the economic credit associated with recovered evaporative emissions.

A. Volatility and Heat of Combustion

Quantifying the relationship between RVP and fuel properties is difficult because of: 1) the complex refinery operations involved in lowering RVP and maintaining octane and other requirements, and 2) the relatively wide range of commercial fuel heats of combustion occurring at any given RVP. Relevant information from two different sources was available to derive independent estimates of the effect of RVP on the heat of combustion. Also, both API and MVMA were requested to submit any relevant information they might have. The two independent analyses and the two submittals are described in the following paragraphs. Table 5-7 details the quantitative results from each for direct comparison.

The first independent analysis used the output of Bonner and Moore's linear programming model, which is being used to estimate the cost of controlling RVP.[1] In addition to RVP and octane, the model generates estimates of other fuel properties, including API gravity, aromatic content, and 50-percent distillation temperature, which can then be used to estimate fuel heat of combustion using a well-accepted relationship defined in ASTM D3338-74. There was significant variation from region to region in the effect of RVP reduction on energy density, resulting from the varying regional compositions of gasoline at different RVPs. The heat of combustion increased 0.22-0.30 percent for a 1-psi RVP reduction and 0.33-0.69 percent for a 2-psi RVP reduction. Weighting the regional effects by gasoline production volume resulted in weighted heat of combustion increases of 0.25 percent and 0.56 percent for a 1- and 2-psi RVP reduction, respectively.

The second independent analysis examined MVMA fuel survey data from January and July gasoline samples taken from 1979-83 (these were available on tape and could be accessed en masse). The heat of combustion of each fuel sample in the surveys was again estimated from the properties of the fuels using the relationship from ASTM D3338-74, as described above. A linear regression was then applied to relate the RVP and the heat of combustion (BTUs/gallon) for the nearly 2,000 summer fuel samples and also for the 4,400 summer and winter fuel samples. For the summer gasolines, a 1-psi reduction in RVP from 11.5 to 10.5 psi resulted in a 0.25 percent increase in the heat of combustion, with a range of 0.22 to 0.28 percent at 90 percent confidence. For summer and winter fuels combined, a 1-psi reduction in RVP from 11.5 to 10.5 psi resulted in a 0.33 percent increase in the heat of combustion, with a range of 0.32 to 0.34 percent at 90 percent confidence. The R^2 was

Table 5-7

Effect of Change in RVP on Change In Energy Density

Source of Information	Percent of Increase in Heat Of Combustion (Btu/gal) RVP 1-psi	 RVP 2-psi
1. Bonner & Moore		
PADD 1	.30	.54
PADD 2	.22	.33
PADD 3	.26	.69
Volumetric Wtd. Average	.25	.56
2. MVMA Fuel Sampling Data		
Summer Fuels	0.25	0.50
Summer & Winter Fuels	0.33	0.66
3. MVMA Submittal		
Calculated Effect	0.32	0.64
4. API Submittal	No calculated results	

only 0.09 for summer fuels and 0.30 for summer and winter fuels combined, but due to the large number of samples, the relationship is quite certain, as evidenced by the tight 90-percent confidence limits. The regression of summer fuels is probably the most appropriate for use here. The winter fuels were included to provide a wider range of RVPs and to test the sensitivity of the results to range of RVP.

The MVMA submittal in this area outlined a first-order analysis of the effect of reduced RVP on fuel heat of combustion.[8] They stated that they were not aware of any test data that would provide a direct relationship between RVP reduction through butane control and vehicle fuel economy; however, they did make some calculations to estimate the effect of butane content on the heat of combustion. They too used the method described in ASTM D3338-74 to estimate gasoline heat of combustion from predicted average properties of the gasoline. They estimated the percent decrease in fuel butane content associated with a 1- and 2-psi change in RVP to be 1.8 and 3.7 percent, respectively. Then, assuming that the composition of the non-butane portion of the fuel would remain constant, they estimated the change in the heat of combustion using the relative heats of combustion of gasoline, and while MVMA did this using three baseline gasolines of various RVP, their analysis ignores the fact that reduced butane content will reduce octane. This octane can be replaced by further processing of the gasoline feed stocks, which will likely reduce the heat of combustion, or by increasing aromatic content, which will likely increase the heat of combustion. MVMA estimated that 1-psi and 2-psi reductions would increase energy density by 0.32 and 0.64 percent, respectively. As these figures are somewhat larger than those estimated using the Bonner and Moore model and the regression of summer fuel RVPs, it appears that increased processing to replace lost butane dominates somewhat and reduces the net heat of combustion increase by about 0.07 percent per psi RVP.

API, in their submittal, stated that there is no predictable relationship between gasoline vapor pressure and gasoline heat of combustion.[9] They state that a number of compositional changes occur in reducing RVP to ensure that the other properties of the gasoline remain in accord with ASTM specifications and that production volume is maintained. As evidence, they cite the fact that the scatter in the heat of combustion of surveyed fuels at a specified RVP is greater than the difference in the heat of combustion between RVPs, and make the determination that any relationship between RVP and the heat of combustion impossible to ascertain. Therefore, they did not submit any conclusions on the net effect of all the factors affecting the heat of combustion accompanying a reduction in RVP, other than to state that the relationship is unpredictable.

As our own assessment of the heats of combustion of MVMA-surveyed fuels indicated, there is a wide variation in the heat of combustion at any given RVP and this variation is larger than the effect of RVP. However, the 90 percent confidence limits on the predicted slope take this variation into account and still predict a range of only 0.25±0.03 percent per psi for summer fuel. Thus, while other factors can overwhelm the RVP effect for any given fuel, on average the RVP effect is quite certain and quantifiable. The fact that the Bonner and Moore estimates fall within this small range, and yet were quite independent, is further support for their accuracy.

Given that the analysis of the survey data and the B&M study yield essentially the same results, the B&M estimates will be used here as it is a forward looking study of lower RVP fuels across the board rather than backward looking survey results. The result is that the heat of combustion is projected to increase 0.25 percent with a 1-psi reduction in RVP and 0.56 percent with a 2-psi reduction.

B. Heat of Combustion and Fuel Economy

As we will use it here, the R-value refers to the percent change in fuel economy for a percent change in fuel heat of combustion allowing for vehicle optimization. While much data on the fuel economy of all types of vehicles exist in the literature, few studies relate fuel economy to fuel heat of combustion and there are none for which the vehicles were optimized for both fuels. Thus, while the effect of heat of combustion on fuel economy should be more consistent and discernible than the effect of RVP on the heat of combustion (once measurement variation is eliminated), few data exist from which to determine accurate estimates. Compounding this is the fact that the random variation in fuel economy measurements is large (e.g., 3-5 percent) relative to the expected change in fuel economy (less than one percent). Two sources of information were used in analyzing this relationship: empirical test data, and theoretical analysis of factors which have been proposed either by industry or ourselves as possibly influencing the value of R. These sources are all discussed in the following subsections.

1. Empirical Test Data

In a letter to EPA dated August 15, 1984, General Motors cited data on the relationship between gasoline heat of combustion and fuel economy (see Table 5-8) which was presented in a Chevron Research Co. SAE paper in 1974, and added that GM testing on more recent systems supported the results presented in the SAE paper.[10,11] The vehicles tested by Chevron were from the 1970 and 1972 model years, and the SAE paper points out that these tests can only give an indication of 1970 and

Table 5-8

SAE 740522 Data on the R Value[11]

Test Vehicle*		Chevron Test Cycle**
1970 NFB		.455
1970 NFB		.750
1970 NFB		.809
1972 NFB		.590
1972 NFB		.380
1972 NFB		.417
	Avg =	.567

---

* Each of the three vehicles in each MY is from a different manufacturer.

** Test cycle information.

Mode Number	Operating Conditions
1	Light acceleration to 35 mph, cruise at 35 mph
2	Medium acceleration 35 to 50 mph, cruise at 50 mph
3	Medium acceleration 50 to 65 mph, cruise at 65 mph, stop
4	Light acceleration to 35 mph, cruise at 35 mph
5	Medium acceleration 35 to 50 mph, cruise at 50 mph
6	Medium acceleration 50 to 65 mph, cruise at 65 mph, stop
7	Light acceleration to 35 mph, cruise at 35 mph
8	Medium acceleration 35 to 50 mph, cruise at 50 mph
9	Medium acceleration 50 to 65 mph, cruise at 65 mph, stop
10	Idle

NOTE: A timer is used to allow 30 s for each mode. Accelerations are made holding manifold vacuum constant. Manifold vacuums are determined for each car to provide light and medium accelerations. Ambient temperature is 72°F.

1972 car performance in general. Their results were based on testing six vehicles with six fuels, repeating each vehicle/fuel-specific test at least eight times. Fuel economy was measured by weighing the fuel consumed and measuring the distance traveled during each test cycle. The heat of combustion of the fuels was calculated using a widely accepted correlation involving API gravity, percent aromatics, and volatility of the gasoline from ASTM-3338. The 1970 vehicles showed an average R defined as the ratio of the percent change in vehicular fuel economy to the percent change in gasoline heat of combustion of 0.67, while the 1972 vehicles averaged only 0.45 for a combined average value of 0.57. The GM submittal did not supply or refer to any data supporting their average value for R resulting from testing on more recent systems, but they did state that the testing yielded R values ranging from 0.1 to 0.9 with an average of 0.5. In their submittal they suggested an overall average R of 0.6.

This value of 0.6 for R was later recommended by GM, Ford, and MVMA in response to questions asked by EPA's Certification Division in the EPA memorandum referenced in the supplemental NPRM on the CAFE adjustment rulemaking.[12,13,14] This ratio of increased fuel economy to increased heat of combustion of 0.6 was recommended for all vehicles (without differentiating between feedback and non-feedback equipped vehicles). The major conclusions of these manufacturers as stated in their January 22, 1985 letters to EPA as well as more recent information are discussed below.

In their letter to EPA, GM summarized data from five vehicles (two with throttle-body injection (TBI) and three carbureted) of model years 1981 and 1984, which are presented in Table 5-9.[12] They include R factors for FTP and highway tests. The method which GM used to measure or calculate the fuel economies of these five vehicles was not stated in the GM letter. The results for FTP testing were an average R of 0.62 for five vehicles, with a range of 0.34-0.89. For the highway test procedure the average ratio was 0.53, with a range of 0.41-0.72. The 0.89 and 0.72 R values were both for a 1984 Pontiac J2000 with TBI.

GM did not explain why R is greater for the FTP tests than for the highway tests. This is not the expected result, since the FTP contains cold operation, where the highway test does not. Typically the cold operation signifies both rich operation and open loop feedback control operation. This combination as will be explained later tends to demand extra fuel thereby decreasing fuel economy and therefore R.

Although the main difference between vehicles abilities to obtain high R values is whether or not they utilize electronic feedback control (EFC), both the TBI vehicles and the carbureted vehicles were probably equipped with EFC operating

Table 5-9

GM Data on the R value[12]

Test Vehicle	R Factor FTP	 HWY
Carbureted Vehicles		
1984 Olds Delta (5.0L, 4bbl.)	0.35	0.51
1981 Olds Cutlass (4.3L, 2bbl.)	0.39	0.41
1981 Chevette (1.6L, 2bbl.)	0.80	0.62
Average	0.51	0.51
TBI Vehicles		
1984 Chevrolet Citation (2.5L, TBI)	0.65	0.41
1984 Pontiac J2000 (1.8L TBI)	0.89	0.72
Average	0.77	0.56
Composite Average (Carbureted and TBI)	0.62	0.53

---

* Testing was not performed all at once, but at three different dates corresponding to the year of each vehicle.

over most of the test cycle, as all GM vehicles of model years 1981 and later used EFC. Therefore, it is possible from this data to distinguish between TBI and carbureted vehicles. If the data from the five vehicles are divided into two groups, as illustrated in Table 5-9, the TBI-equipped vehicles showed higher R values (0.77 vs. 0.51 for the FTP and 0.56 vs. 0.51 for the highway test) than the carbureted vehicles. The composite data have an average R of 0.58, which may be rounded off to 0.6. However, the fact that the TBI vehicles showed higher R values than the carbureted vehicles and the statement by GM that R can approach 1.0 for some operating conditions (i.e., steady state) indicate that it may be appropriate to assume an R higher than 0.6 for fuel-injected (FI) vehicles. The better performance of the FI vehicles may be due to the tighter control over fuel metering and shorter feedback delay time which fuel injection offers.

In a direct response to EPA's question, "Is it appropriate and/or possible to account for the effect of fuel energy content on the vehicle's energy efficiency? If so, how should this be done?" GM supplied no other data than that in Table 5-9 and a reference to SAE paper no. 740522 and recommended an R of 0.6.

Ford also recommended that an R = 0.6 be adopted to represent the 1980-85 model year vehicles.[13] The Ford letter of 1/22/85 goes on to state that future model year vehicles could respond differently and, thus, should be evaluated separately if warranted by future fuel specification changes. Ford based their conclusion on repeated test results from four different vehicles with different engines and control systems using two different fuels. Twelve LA-4(Hot) and 12 HWFET tests were conducted on each vehicle and with each fuel for a total of 192 tests. The method used to determine the fuel economies of these vehicles (volumetric measurement or carbon balance calculation) was not stated in the Ford letter. These results are presented in Table 5-10.

One of these four vehicles was equipped with electronic fuel injection (EFI), always accompanied by EFC, while the rest were designated NFB for non-feedback vehicles. The R value for the EFI vehicle for the hot-start test was 0.75. For the hot-start portion of the urban driving cycle LA-4(Hot) fuel evaluation and the highway fuel economy test (HWFET) fuel evaluation analyses, the R values were 0.71 and 0.84, respectively. The other three vehicles were NFB with average R values of 0.35 for the LA-4 (hot) analysis, and 0.67 for the HWFET fuel evaluation analysis. These R values are significantly lower than those resulting from testing the EFI vehicle. MOBILE 3 projections predict that by 1990 nearly 90 percent of gasoline-fueled vehicles in-use will have EFI or will be feedback-equipped carbureted vehicles. Thus, based on

Table 5-10

Ford Data on Ratio of Percent Change in Fuel Economy to Percent Change in Energy Density[13]

Test Vehicle	M-H HS*	CVS-H*	HWFET*	CVS-C/H*
w/o Feedback Controls				
3.8-216	0.5974	0.2168	1.1837	
1.6-602	0.6178	0.5574	0.7173	
5.0-807	0.2095	0.2687	0.1161	0.846
Average	0.4749	0.3476	0.6724	0.846
W/Feedback Controls				
1.6-343 EFI	0.7502	0.7082	0.8403	1.065
Composite Average (Feedback and Non-Feedback)	0.5437	0.4378	0.7143	0.955

---

* M-H Hot-Start = City (55%) and HWFET (45%) combined to yield an overall average value.
CVS-H = City test cycle - hot-start.
HWFET = Highway test cycle.
CVS-CH = City cycle test - cold-start.

the Ford data, it is reasonable to assume an R value higher than 0.6 for vehicles in use in 1990, the majority of which will use EFC.

The MVMA letter of January 22, 1985 analyzes the data submitted by GM and Ford and reaches the same conclusion; 0.6 is a reasonable value for R.[14] The MVMA letter does not propose a higher R value for feedback equipped vehicles vs. non-feedback equipped vehicles.

Ford also mentions in its March 27, 1986 submittal[15] some additional data on four more late model year vehicles which suggested a higher value for R than 0.6 may be more appropriate. This information obtained from SAE paper 860533[16] is presented in Table 5-11. The four 1984 and 1985 model year prototype vehicles were tested in triplicate over the entire FTP test cycle. Three of the four vehicles utilized closed loop feedback control while the other one did not. The combined average R value was an extremely high 1.850. The paper did not actually calculate the R value, therefore it gave no explanation for the high value, nor did Ford in its submittal provide any additional comments.

API, in their April, 1986 submittal[17] presented single run test data collected by Chevron on 12 1981-1983 vehicles of varying control strategy shown in Table 5-12. The vehicles were tested over the FTP cycle, however, ambient temperatures were adjusted to 43°F and 55°F in an attempt to simulate actual morning startup temperatures in the LA basin. Although there was no standard FTP data taken to compare to, the R values determined seemed to be unusually low due to the cold temperatures. But rather unexpectedly, the R values at 55°F were much lower for many of the vehicles than at 43°F, particularly the carbureted vehicles. This fact remains unexplained. As data were not taken at standard conditions, it is of limited use when comparing it to other data. However, it may be of some use in explaining the causes for lower R values. Besides the temperature affect, there appears to be a strong benefit to closed loop control when looking at the 55°F FTP data. The 43°F data also shows an improvement under closed loop control.

In the same submittal, API presented another earlier set of data of tests done on eight open-loop 1973-1976 model year vehicles. The testing was once again performed by Chevron (see Table 5-13). This time the vehicles were tested over the FTP with ambient temperatures of 75°F and 55°F. The 75° FTP seemed to match within reason other standard condition FTP data, while the 55°F FTP data suggests that the previous data at that temperature for open loop vehicles may have been too low. This data once again supports the argument for possibly lower R values due to cold temperatures, with a greater effect on open loop vehicles than on closed loop vehicles.

Table 5-11

Ford Data on the R Value[16]

Test Vehicle	City	HWY	Harmonically Weighted
1984 1.6L NFB	1.132	1.345	1.211
1985 2.3L FB	4.419	1.698	3.434
1985 3.8L FB	-.637	-.489	-.570
1985 5.0L FB	2.861	4.350	3.323
AVG.	1.944	1.726	1.850

Table 5-12

API Data on the R Value[17]

Test Vehicle		43°F FTP	55°F FTP
Open Loop			
81 Aries		.243	-1.707
81 Datsun		1.116	- .210
82 Escort		.198	-1.115
83 Accord		.530	- .269
83 SR5		.009	.113
	Avg.	.419	- .638
Closed Loop			
82 Cavalier		.034	.383
82 Ciera		.430	1.887
82 Corolla*		**	.376
83 Cavalier		.951	**
83 Maxima		.032	.335
83 Cutlass		1.022	.451
83 GLC*		1.117	.642
83 Corolla		.002	**
83 Lincoln*		**	1.408
	Avg.	.513	.783
Composite Avg.		.474	.191

---

* Level of feedback control assumed to be closed loop.

** Not tested.

Table 5-13

API Data on the R Value[17]

Test Vehicle		FTP @ 75°F	FTP @ 55°F
73 Plymouth		.124	.810
73 Pontiac		1.114	.957
73 Pontiac*		.511	-.005
74 Volkswagen		.544	.341
75 Chevy		.614	.194
75 Ford		1.550	.615
75 Pinto		.930	-1.189
76 Olds		.793	- .458
	Avg. =	.773	.158

---

* Same vehicle as the one above, but with a new carburetor.

When all of the data are combined and weighted for the year 1990 in which 90 percent of the vehicles in-use are estimated to be closed-loop feed back controlled (see Table 5-14), then the data predicts an R value of 1.075. This is actually greater than one, however, it is based on a combined average of the FTP and Metro-Highway (a combination of the FTP and HWFET cycles) data. While the R value for the Metro-Highway cycle would be expected to be higher than for the FTP due to lower cold start interference, the GM data in Table 5-9 did not support this fact. Thus, combining the data to obtain one value is not thought to introduce significant errors. Even at the 55°F FTP test cycle condition, the predicted R value is 0.69; greater than the 0.60 estimate given by all of the industry sources as a good estimate. Only when the temperature for the FTP test cycle gets to 43°F does a lower value of 0.504 appear. However, there is such a broad range in the data, that it is impossible to rely on these values to any great extent.

2. Error in Testing

The broad range in the test data for R value suggests that there may be sources of error in the testing. Some are possibly procedural problems, while others are simply the uncertainty of measured values. First, in determining the effect of a reduction in gasoline RVP on vehicular fuel economy, it is necessary to evaluate the vehicle that will be operating on this lower RVP fuel, and the design optimization of that vehicle. Automobile manufacturers are concerned with obtaining the highest fuel economy possible to meet CAFE requirements and advertise high fuel economies to attract consumers. Vehicular fuel economy figures are the result of testing over the EPA FTP and HFET cycles, in which the vehicles are operated on Indolene, a 9-psi RVP gasoline. Therefore, the manufacturers presumedly optimize the vehicle fuel systems to operate on Indolene, to maximize the fuel economy figures resulting from the FTP test cycle. As a result, when vehicles are operated on a different fuel to determine the affect this has on its fuel economy, the resulting value will be erroneously low since the vehicle was not re-calibrated to optimize for the new fuel. Thus the R value resulting from this testing will also reflect this underestimated fuel-economy.

A second source of error in this testing is that the R value is defined as the percent change in fuel economy to the percent change in fuel heat of combustion. But vehicle fuel economy is a function of many more fuel properties than just the fuel heat of combustion. This alone can explain many of the excursions in the test data. Two studies could use fuels with the same change in fuel heat of combustion but relatively large differences in other fuel properties such as specific gravity, hydrogen/carbon ratio, and RVP. Thus, the resulting R values determined will vary dramatically. For example, the 0

Table 5-14

Summary of All Data on R Value

Open Loop Vehicles Cycle	No. Vehicles	R Value
Std FTP/M-H	12	.735 ± .411
43°F FTP	5	.419 ± .432
55°F FTP	13	-.148 ± .803
Chevron Cycle	6	.567 ± .180

Closed Loop Vehicles Cycle	No. Vehicles	R Value
Std FTP/M-H	9	1.113 ± 1.356
43°F FTP	7	.513 ± .507
55°F FTP	7	.783 ± .615

Composite for 1990 (90% Closed Loop)

Cycle	R Value
Std FTP/M-H	1.075 ± 1.262
43°F FTP	.504 ± .496
55°F FTP	.690 ± .634

to 3.5 psi change in test fuel RVP that exists in the studies presented thus far resulted in a change in the fuel heat of combustion of from 0.4 to 1.6 percent. However, this same range in RVP's may result in an increase in evaporative emissions to the canister of from 0 to 65 percent. Since the vehicle evaporative recovery system is not modified to handle this large increase, the resulting effect on the fuel economy measurements could overwhelm the effect of the heat of combustion.

Not only are there intrinsic sources of error in the test procedure, but also in the estimation of fuel parameters used in the testing. According to API, method D3338 which is commonly used for calculating the heat of combustion of gasoline, has an error range of ± 0.74 percent. In addition, method D1198 for calculating the specific gravity of the fuel has an error range of ± .0012 between labs (roughly ± 0.2 percent). When typical values are assumed for the heat of combustion and specific gravity, the two sources combine into an error of ± 0.90 percent for the heat of combustion per gallon of fuel. This compares to the change in the heat of combustion of only approximately 0 percent to 1.6 percent due to RVP differences in the test fuels of 0 to 3.5 psi respectively. These two values translate into a difference in the calculated heat of combustion between the two fuels tested of at best 1.6 ± 1.8 percent. This range of error can have serious consequences when trying to determine the value of R for such a small change in the heat of combustion.

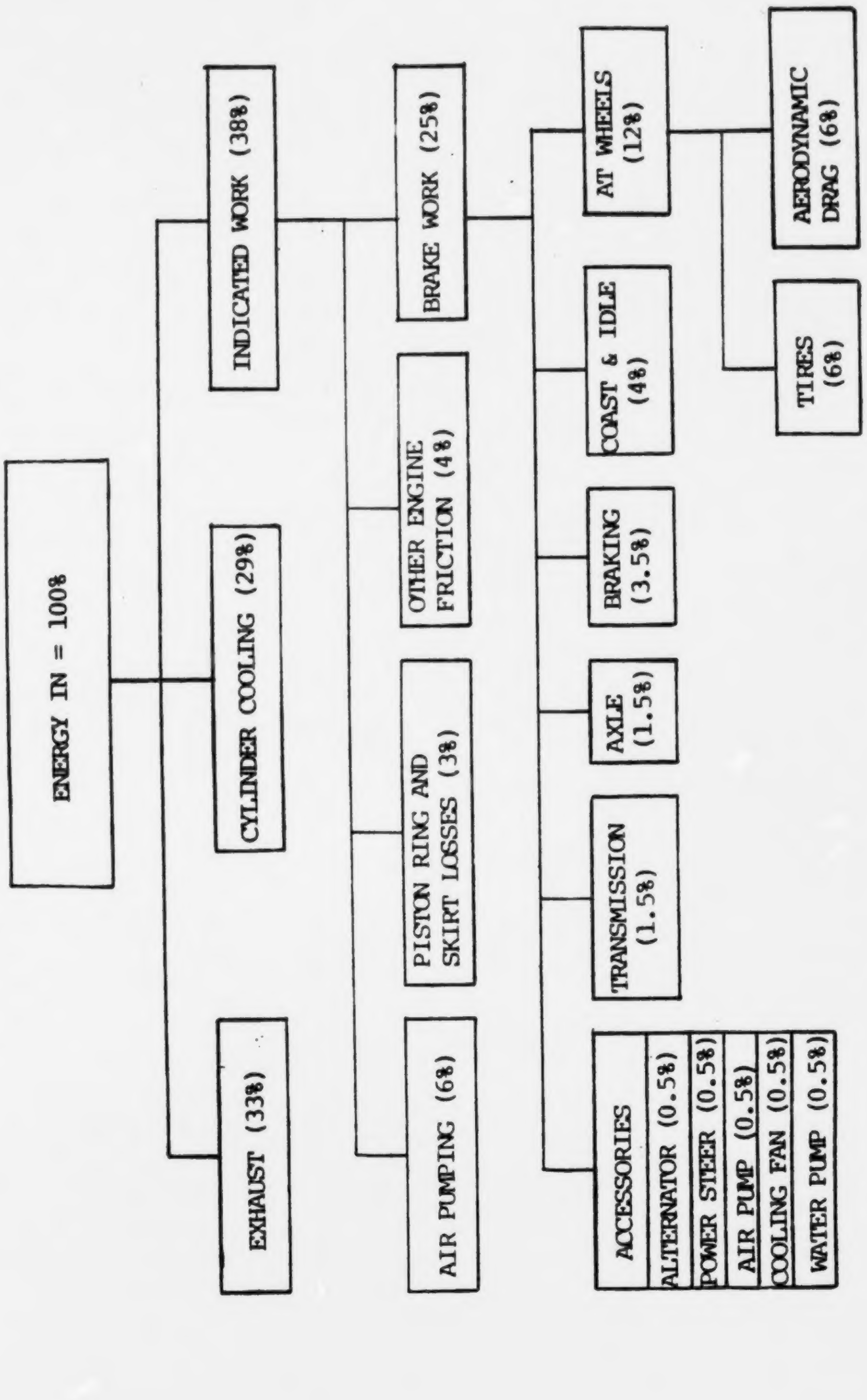
In addition, the fuel economy change of the vehicle using the two different fuels is only on the average 1.6 percent if we assume a value of R equal to 1 (a smaller value for R would decrease this value still further). Thus, the fuel economy measurement must be determined to a high degree of accuracy to distinguish between the two fuels. Since the accuracy of any one fuel economy measurement is at best within ± 1 percent, then it is once again extremely difficult to accurately determine the change in fuel economy and therefore the value of R by actual test methods even with replicate testing. For this reason theoretical analysis remains as what we believe to be the only viable alternative. However, the test data described previously may still be useful in corroborating the results of theoretical analysis.

3. Theoretical Analysis of the Value of R

There are many parameters which must be taken into account when analyzing the fuel economy of a vehicle. But in this instance we are only interested in those things which are affected by a change in the fuel properties. Figure 5-2 shows an approximate distribution of energy consumption for a typical vehicle. In the ideal case, these fractions will remain constant; independent of changes in the fuel properties. This

Figure 5-2 [21]

VEHICLE ENERGY DISTRIBUTION


ENERGY IN = 100%
EXHAUST (33%)
CYLINDER COOLING (29%)
INDICATED WORK (38%)
AIR PUMPING (6%)
PISTON RING AND SKIRT LOSSES (3%)
OTHER ENGINE FRICTION (4%)
BRAKE WORK (25%)
ACCESSORIES
ALTERNATOR (0.5%)
POWER STEER (0.5%)
AIR PUMP (0.5%)
COOLING FAN (0.5%)
WATER PUMP (0.5%)
TRANSMISSION (1.5%)
AXLE (1.5%)
BRAKING (3.5%)
COAST & IDLE (4%)
AT WHEELS (12%)
TIRES (6%)
AERODYNAMIC DRAG (6%)

will result in identical engine efficiency, and therefore, the energy required to drive the vehicle for one mile will remain constant, resulting in an R-value of 1.0. Unfortunately, the real situation is such that some of these fractions will vary due to changes in the fuel properties. This in turn will cause the value of R to vary.

Throughout their comments on the subject of R-value, industry supplied several reasons in support of their assumed R-value of 0.6. These are listed in Table 5-15 in order of what is thought to be their relative importance.

The first point, higher losses (lower efficiency) in the engine cylinders due to higher flame temperatures, requires in-depth quantitative analysis to evaluate to what degree it actually affects the value of R. A description of this analysis follows, however, it is based on the change in heat of combustion rather than on the change in maximum flame temperatures. This is believed to better represent the average losses in the cylinder.

A model derived for the ratio of the heat loss in the cylinder of an engine to the heat of combustion of the fuel was used to determine the change in heat losses from the cylinder of the engine due to the change in fuel properties with RVP control.[18] Table 5-16 shows the fuel properties used in this analysis. Values for the 9.0 RVP fuel and butane were assumed, and properties for the other gasoline fuels were weighted based on the fuel butane fraction. Table 5-17 shows the model which was used to determine the heat losses, and describes the variables which are used in the model as well as providing the values assumed for this analysis. The results indicate that the fraction of heat losses to the cylinder walls increased by approximately 0.0247 percent from 19.6309 percent to 19.6358 percent of the total energy input with the lower RVP, higher heat of combustion fuel.

This increase can then be applied to the value of 29 percent previously assumed for the losses to the engine cylinder from Figure 5-2. If we also assume that this same increase applies to the heat losses to the exhaust (33 percent), then the energy required with the new fuel to move the vehicle one mile can be determined from the following equation:

$$1)\quad Q_2 = Q_2(.62)\,\frac{(Q_{cyl2})}{(Q_{cyl1})} + (.38)(Q_1)$$

Where:

Q= Energy required to drive vehicle one mile
1= Original base case fuel
2= New fuel
Q_{cyl}= Calculated fraction of energy lost to the cylinder

Table 5-15

Reasons Given to Support a Low R Value

1. Increase in flame temperature due to increase in aromatics content causing higher losses (low efficiency) in the cylinder. (Closed loop affect)

2. Cold F/A enrichment and open loop operation of feedback systems at cold start. (Open loop affect)

3. Test cycle transients. (Open loop affect)

4. F/A ratio shifts slightly richer. (Closed Loop affect)

5. Even late model vehicles do not fully use a change in fuel heat of combustion under conditions where they operate rich, including idle, acceleration, and cold start and warm up. (Open loop affect)

6. Higher density fuels have higher concentrations of aromatics which increase viscosity, surface tension and latent heat of vaporization. These tend to decrease evaporation rates with a resulting decrease in fuel mixture homogeneity and quality of cylinder to cylinder distribution. (Closed loop affect)

7. High density low H/C fuels may run at higher equivalence ratios resulting in lower efficiency and lower R. (Closed loop affect)

8. Increased friction. (Closed loop affect)

Table 5-16

Fuel Property Change Summary*

Fuel Parameter	Butane	11.0 RVP Gasoline	9.0 RVP Gasoline	11.5 RVP Gasoline	13.9 RVP Gasoline	Propane	Methanol
Heat of Combustion(Q_c) in BTU/lb	19643	18532	18500	18540.9	18580	19770	8580
Specific Gravity (Density in lb/gal)	0.5836 (4.87)	0.7349 (6.13)	0.7405 (6.18)	0.7335 (6.12)	.7267 (6.06)	.49973 (4.1705)	.796 (6.64294)
Stoichiometric F/A	0.64516	0.06884	0.06897	0.06881	0.068665	0.064222	0.155552
Liquid Viscosity (20°C) in centipoise	0.18 **	0.342	0.348	0.340 cp	0.333 cp	----	----
Specific Heat of Charge in BTU/lbm °R	0.2847	0.28266	0.2826	0.28267	0.28274	0.2856	0.2979

---

* Changes for gasoline based strictly on replacement of 3.6 vol. percent (2.8 weight percent) butane with gasoline.

** Since butane is normally a vapor at 20°C, this is an extrapolation from 0°C.

Table 5-17

Modeling Equation:

$$Q_{cyl} = \frac{K_e\ (T_g - T_c)(1+F)\ G_g^{-.25}}{FQ_c}$$

Term	Description:	Assumed Value:
Q_{cyl}	Heat lost from the gases in the cylinder Divided by the Heat of combustion of the fuel (used in the cylinder)	
K_e	$(10.4\ K_g/b)\ (b/mg_o)^{.75}$	0.4073
K_g	Gas conductivity at T_g	$8.5\text{x}10^{-6}$ BTU/Sec ft°F
b	Cylinder bore	2.5"
mg_o	Gas viscosity at Tg	$22\text{x}10^{-6}$ lbm/sec ft
T_g	Mean effective gas temperature $72 + \frac{(693*Q_{c2}*F_2*C_{p1}*(1+F_1))}{Q_{c1}*F_1*C_{p2}*(1+F_2)}$	765°F for base case for new case
T_c	Mean effective coolant temperature	170°F
F	Fuel-air ratio	Stoichiometric (See Table 5-16)
Q_c	Heat of combustion per unit mass of fuel	(See Table 5-16)
G_g	Gas flow per unit time per unit piston area = $\frac{P(1+F)\ 2545}{3600\ (\#cyl)(Ap)(F)(Q_c)(N_t)}$	1.14305 ^{ibm}/sec f^{2} @ low RVP 1.14439 @ high RVP
P	Engine horse power	100 HP
N_t	Thermal efficiency of the engine	0.38
A_p	Piston area = $\pi(b/2)^2$	0.034088 ft^{2}
#Cyl	Number of cylinders	4
Cp	Charge Specific Heat	(See Table 5-16)
1	Base Case	
2	New Case	

The last term remains constant over fuels, since the magnitude of the individual work necessary to move the vehicle one mile does not change at this point in the analysis. Solving the equation for the ratio of energy required to drive the vehicle in the new case as opposed to the base case (i.e. Q_2/Q_1) yields a value of 1.000403. Since this is greater than 1.0, the energy required to move the vehicle with RVP control has increased, which is to say that the value of R has decreased below 1.0. The fuel economy of the vehicle with the new fuel can now be determined from the following equation:

$$2)\quad FE_2 = \frac{FE_1 \times Q_1 \times Qc_2}{Qc_1 \times Q_2}$$

Where:
FE = Fuel economy
1 = original base case
2 = new fuel case
Q_c = fuel heat of combustion per gallon of fuel
Q = as before

The value for the original fuel economy for new vehicles in 1988 is assumed to be 28.35 miles per gallon based on Mobile 3. The new value for the fuel economy from the above equation is then 28.506 miles per gallon. Once this number is determined, the value of R for this situation can be determined from the following equation:

$$3)\quad R = \frac{FE_2 \div FE_1 - 1}{Q_{c2} \div Q_{c1} - 1}$$

The resulting value for R is 0.931.

The second point listed in Table 5-15, cold F/A enrichment during open loop feedback control also deserves some consideration. Extra fuel is required during a cold start in order to get enough fuel evaporated in the cylinder to enable combustion. If you now have a fuel with lower volatility, you must use still more fuel in order to get the minimum amount vaporized. This greater amount of fuel has a higher heat of combustion causing still a larger use of fuel energy.

Unfortunately, data were not available on a real time basis for the fuel consumption during a cold start over the open loop portion of the test for high and low RVP fuels. It was thought that a comparison of bag 1 versus bag 3 of the FTP could give an overall estimate of the cold start open loop effect. However, this would also include the effects of cold engine temperature during closed loop operation which as discussed later, should not affect the value of R. Therefore, it would be a severe over-estimation of the cold start open loop effect. In addition, estimation of the fuel volatility effect proved to be very difficult due to lack of knowledge of actual required F/A ratios over the period of cold start, open loop performance.

Thus, although this cold start, open loop operation effect on the value of R may be real, it is not possible to determine its magnitude from available data. In addition this effect might be compensated for by the low RVP, higher energy content fuel raising engine temperatures faster than the higher RVP fuel. This in turn would decrease the time period required for open-loop operation during the cold start, saving fuel and therefore raising R.

The third point presented in Table 5-15 which may reduce the value of R, is test cycle transients. There can be no doubt that test cycle transients affect the efficiency of the engine. However, the value of R is a ratio of the efficiency of an engine with one fuel to the efficiency of the engine using a base fuel. As the test cycle transients are not a fuel property, they by themselves cannot affect the value of R. However, since the fuel with RVP control has a higher volumetric heat of combustion, and transients cause F/A ratio enrichment which "wastes" fuel, the first thought is that you are now "wasting" higher energy content fuel, therefore decreasing your R value. But even though you are "wasting" higher energy content fuel, you are also getting more work from the higher energy content fuel which is burned. For this reason the efficiency of the engine during transients, although decreased relative to steady state, should still be constant across fuel parameters resulting in no change in the value of R. This may be supported somewhat by the conflicting data from Ford and GM. Ford showed a decrease in R over a cycle with more transients while GM showed an increase (see Tables 5-9 and 5-10).

The fourth point states that the F/A ratio shifts slightly richer. Although the variability between fuels is large, the primary effect of reduced butane content supports this statement. The changes in fuel properties as seen in Table 5-16 reflect weighted averages of replacement of 3.6 volume percent butane with gasoline. The specific gravity increase of 0.76 percent will cause 0.76 percent more mass of fuel to be metered since it is metered volumetrically. However, not all of this added fuel enrichens the F/A mixture since the F/A ratio required for stoichiometry has also increased by 0.19 percent. Assuming that most vehicles by 1990 will have closed loop feedback control utilizing oxygen sensors, the vehicles entering the market should be able to adjust back to stoichiometry for this slight deviation during operation in the closed loop mode causing no detrimental effect on the value of R. In addition, the open loop control set point of new vehicles can be adjusted to account for the change in fuel properties resulting in no added losses. Current in-use vehicles both closed loop and open loop, however, will not be able to compensate for the change in fuel properties when they operate in the open loop mode. In addition, as will be seen later, the sensitivity of our modeling to the F/A ratio is such that the heat losses to the cylinder walls are affected by the F/A ratio in a manner such that with the fuel composition change we are expecting to see, the value of R should actually increase instead of decrease.

The fifth point, which emphasizes the inability of even late model vehicles to utilize the change in fuel heat of combustion when they operate rich, is actually the sum of previous discussions focusing on transients and cold start. Thus, no further discussion of it is needed.

Warm-up as it pertains to open-loop operation was discussed above under open loop operation due to cold start. However, warm-up can also be used to describe the condition after closed loop operation begins, but when engine temperature has not yet stabilized. In this case, the higher combustion temperatures due to an increased heat of combustion content will cause greater losses per unit time to the still cool engine in the same manner as discussed under point number one. However, these higher combustion temperatures will also decrease the time for vehicle warm up and the time to reach equilibrium. For this reason, the effect of closed-loop warm-up is not predicted to have any detrimental effect on the value of R.

For the point made of idle operation equation 1 can be modified to account for the added loss associated with the increase in fuel heat of combustion for the periods when the vehicle is operating at zero percent efficiency. From Figure 5-2, these periods (coast and idle) represent roughly 4 percent of the energy consumption of the vehicle with the base case fuel. This should increase proportionately to the volumetric increase in fuel heat of combustion since the fuel is metered volumetrically. Therefore, equation 1 becomes:

$$4)\ Q_2 = Q_2(.62)\left(\frac{Q_{cyl2}}{Q_{cyl1}}\right) + Q_1\ (.04)\left(\frac{Q_{c2}}{Q_{c1}}\right) + .34Q_1$$

Once again, solving for Q_2/Q_1 and substituting into equations 2 and 3 yields a new value for R of 0.826.

This, however, is not precisely accurate, for there are two different conditions, cold idle and hot idle. The case can be made that for the hot idle condition the manufacturer can change the set point of open loop idle operation to adjust the flow of fuel in proportion to the change in energy content. Therefore, no additional losses will occur. However, as has been discussed, for a cold start, additional fuel is required over and above the normal amount due to the decreased volatility of the fuel. So, in the case of cold start idle, not only can the amount of fuel not be decreased in proportion to the increase in energy content, but it must be increased. Thus, cold idle could have a detrimental effect on the value of R. This detrimental effect will depend directly on the length of time at which the vehicle is allowed to idle. As before, however, a benefit may be derived from the higher engine temperatures due to the higher energy content fuel. These increased temperatures should decrease the time required for open-loop operation following idle, thereby reducing the total losses due to the cold vehicle operation.

The above equation probably over-estimates the effect of hot idle, and may under-estimate the effect of cold idle operation. Although the hot portion is probably much greater than the cold portion, no truly accurate estimate can be made. For this reason equation 4 remains as the best available estimate of the effect of idle.

The sixth point covers a broad range of topics including the estimated changes in fuel density, viscosity, surface tension, and latent heat of vaporization; the effects that these changes have on fuel vaporization rates; and the effect that this has on fuel mixture homogeneity and cylinder to cylinder distribution. Tables 5-16 and 5-18 show the average expected changes in fuel properties due to the primary cause of a reduction in butane with RVP control. Although other secondary causes can possibly dominate the effect of the change in butane content, this is the only one which is easily quantifiable and it may accurately represent the average changes in the fuel properties due to RVP control.

The fuel properties in question such as surface tension and latent heat of vaporization not listed in Table 5-16 are not easily quantifiable as they relate more to properties of the fuel/air mixture. In any case, the changes in these properties will be slight in comparison to liquid fuel changes since the air properties will tend to dominate. The percent vaporized at 330°F is a value that should lump the effects of these fuel/air properties together.

The change in percent vaporized at 330°F is so slight (0.055 percent) as can be seen in Table 5-18 that any affect of the change in fuel evaporation rates on fuel mixture homogeneity or cylinder-to-cylinder distribution would be unnoticeable. However, the change in liquid fuel viscosity although still not large, is significant with an increase of 1.7 percent. But its effect is only seen in the fuel distribution system of the vehicle and is related to efficiency (and, therefore, R value) through the increased load on the fuel pump. However, since most fuel pumps for fuel injected vehicles run at constant load, pumping more fuel than is needed to the fuel injectors and recirculating the rest back to the

Table 5-18

Change in Percent Vaporized at 330°F[1]

	Base	Low RVP (-2)	Diff.
PADD 1	94.685	94.942	+.257
PADD 2	93.748	93.920	+.172
PADD 3	92.543	92.314	-.229
Weighted Avg.	93.131	93.076	-.055

NOTE 1: Values are for pool average.

NOTE 2: Due to the marketing of butane, we would not expect butane to be used in the refineries. Therefore, open NGL was assumed most representative.

NOTE 3: PADD Volumetric Distribution

1) 0.0883
2) 0.2925
3) 0.5399
4) 0.0793 (excluding Calif.)

fuel tank, the increase in viscosity will not cause any increased load on the vehicle. It will merely cause a slight decrease in the amount of fuel which is recirculated. This small decrease should not have any detrimental effect on the engine operation. A second place where viscosity can effect vehicle operation is in the fuel injector, where an increase in viscosity could dampen the flow of fuel out of the fuel injector during transient operation. This would have the effect of increasing vehicle efficiency, and therefore raising the value of R. However, since much of the fuel flow through an injector is in the turbulent flow region, it is for the most part independent of the fuel viscosity. Therefore, it too has a negligible effect, and the effect of fuel viscosity on the value of R can be ignored.

The seventh point states that higher equivalence ratios may cause lower R values. While it is true that the stoichiometric F/A ratio increases as has been discussed above, it is not true that the equivalence ratio increases. The equivalence ratio is the ratio of the F/A ratio to the stoichiometric F/A ratio. Since the stoichiometric F/A ratio is increasing, the equivalence ratio should actually decrease with RVP control. The only exception is when the actual F/A ratio changes proportionately (which is what we are assuming for modern vehicles) in which case the equivalence ratio remains constant. Therefore, the presumption that equivalence ratio is increasing is erroneous and this is not a valid reason for a low R value.

The final point, increased friction, as it relates to the vehicle, is independent of the fuel being used since the friction per mile of travel remains constant. Therefore, it is irrelevant in relation to the R value. The engine friction which represents 13 percent of base case energy consumption, however, does not necessarily remain constant. The friction per mile is proportional to the number of cylinder strokes, and this in turn is a function of the power output per stroke. For this reason, the engine friction should change in proportion to the amount of work available from the fuel in the cylinder while maintaining the necessary stoichiometry. This ratio is a function of the fuel-air ratio, the heat of combustion of the fuel per unit mass, and the change in the fraction of energy lost to heat. Therefore, including the effect of fuel parameters on engine friction per mile driven into equation 4 yields:

$$5)\quad Q_2 = Q_2\,(.62)\left(\frac{Q_{cyl2}}{Q_{cyl1}}\right) + Q_1(.04)\,\left(\frac{Q_{c2}}{Q_{c1}}\right) +$$

$$Q_1(.13) * \left(\frac{Q_{f1} * F_1 * Q_{cyl2}}{Q_{f2} * F_2 * Q_{cyl1}}\right) + .21Q_1$$

Where: Q_f=the fuel heat of combustion per unit mass
F =the fuel-air ratio
(Other parameters as before)

Solving this equation for Q_2/Q_1 and substituting into equations 2 and 3 yields a value for R of 0.82.

This represents a maximum value that the value of R can take on due to the added heat losses associated with the increase in the heat of combustion of the fuel and the change in other fuel properties associated with a 2 psi reduction in RVP. It should be noted, however, that this is the maximum only for the fuel property values used in this analysis which are averages predicted for a high and low RVP fuel. Actual fuel data used in a similar manner can far exceed the 0.82 value cited here.

An analysis performed on the model to test for its sensitivity to the various fuel parameters involved shows that holding everything else constant, changing the heat of combustion of the fuel alone has little or no effect on the value of R. The change in cylinder temperature associated with the change in heat of combustion seems to offset it nearly equally resulting in a constant value of approximately 0.2 for R. Thus the difference between this value and the previous value of 0.82 must be due to other fuel parameters. The change in fuel heat of combustion alone cannot be used to accurately define the value of R.

The change in specific gravity has a large effect on the value of R as can be seen in Figure 5-3. In the range of realistic changes in the heat of combustion and the specific gravity the R value can be expected to increase, thus explaining part of the increase in the value of R from 0.2 to 0.82.

The fuel-air ratio (F/A), which is used as an input a number of times into the heat loss modeling equation and its constituents, also has a large effect on the value of R as can be seen in Figure 5-4. The effect of F/A is highly dependent on the change in the heat of combustion of the fuel, but in the range that we would expect for the changes in fuel properties with RVP control, the effect of F/A would be to greatly increase the value of R.

Figure 5-5 shows the overall effect of changes in the heat losses in the engine due the changes in fuel properties. The response of the R value to the change in heat losses appears to be linear. The rather flat slope of the line indicates that even if the value which was calculated for the change in heat losses used in the previous analysis was incorrect, a gross error in this estimate would not significantly effect the resulting value of R.

Figure 5-3

Sensitivity to Sg

for varying heat of combustion/lb. fuel

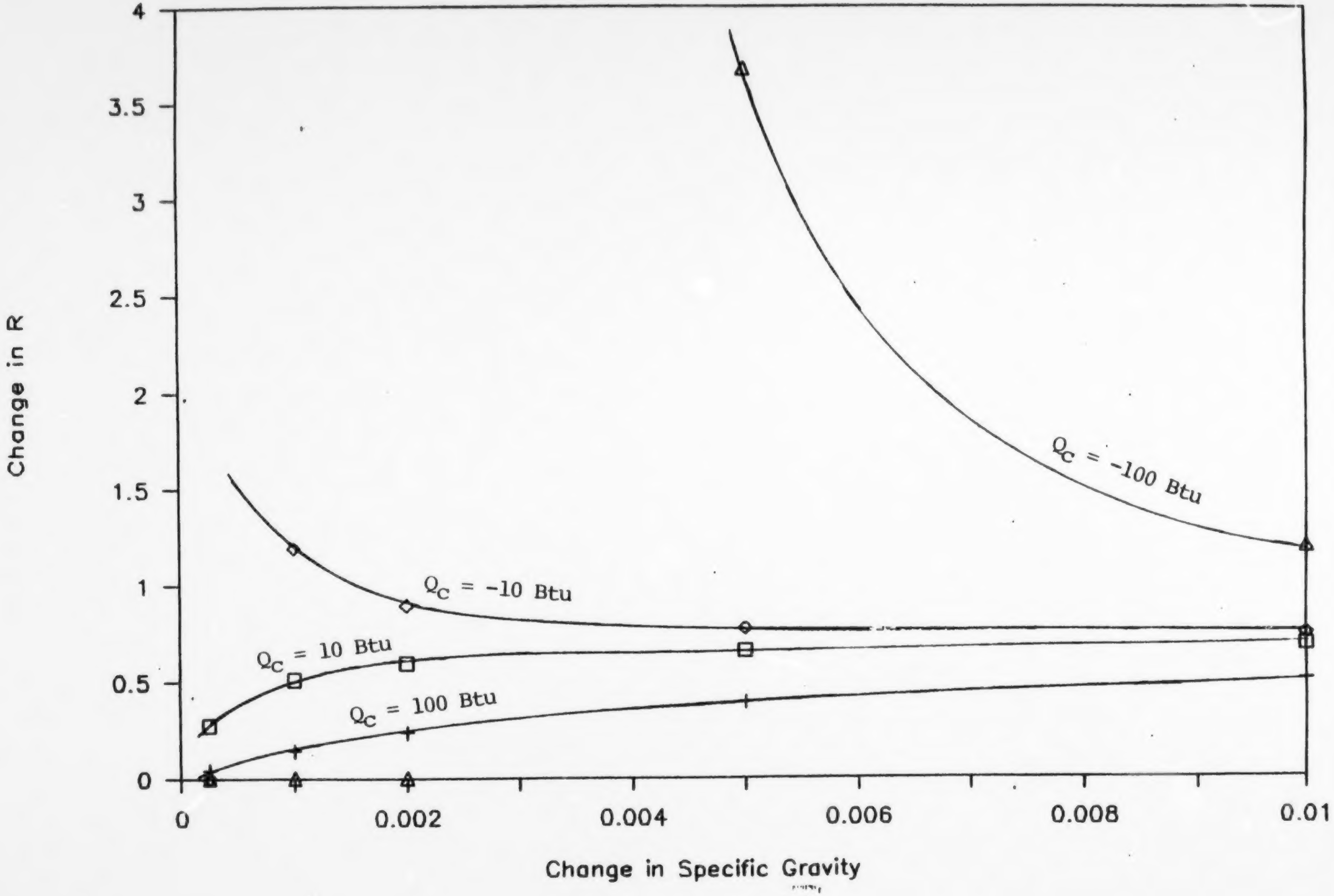


Figure 5-4

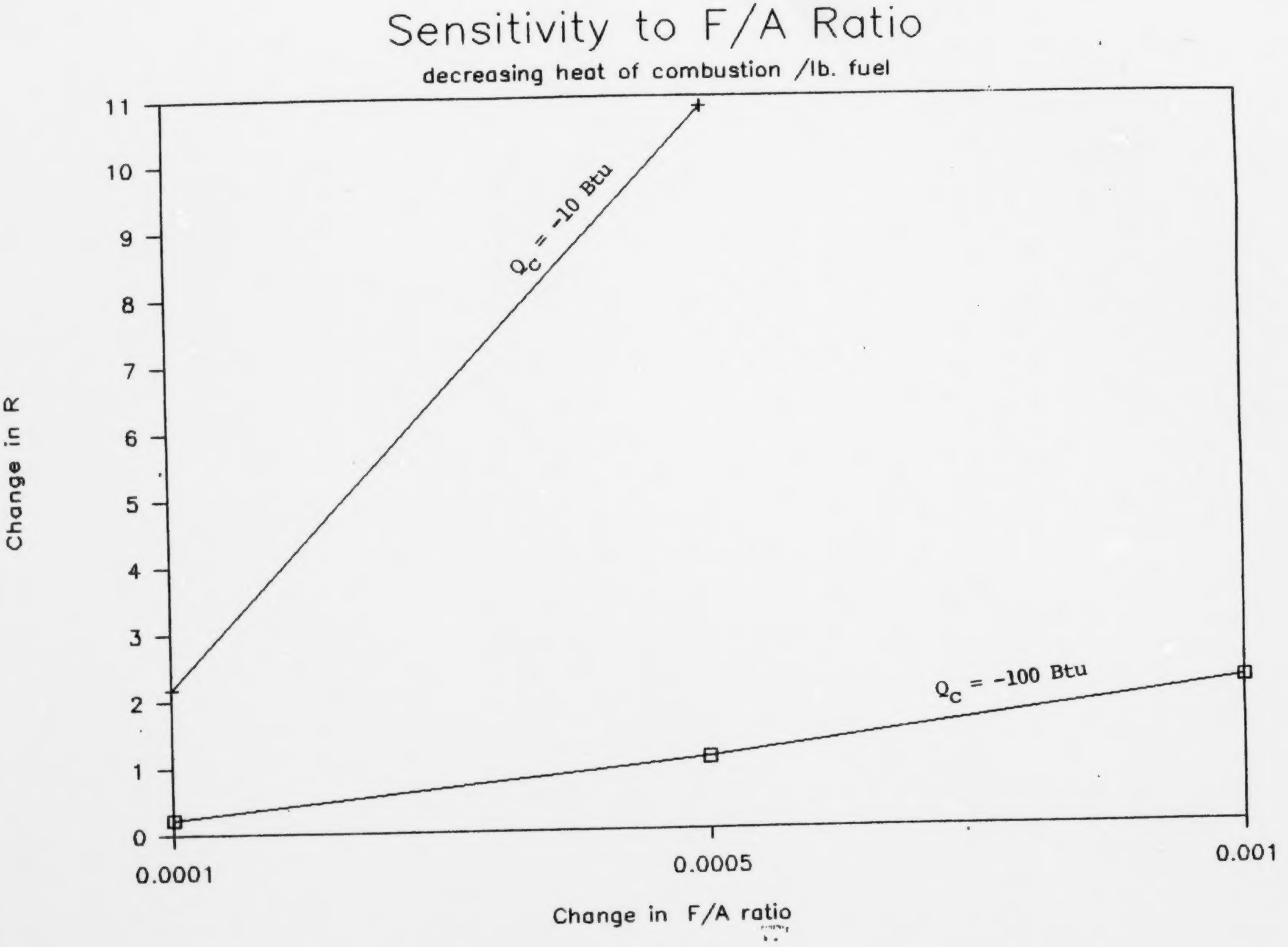
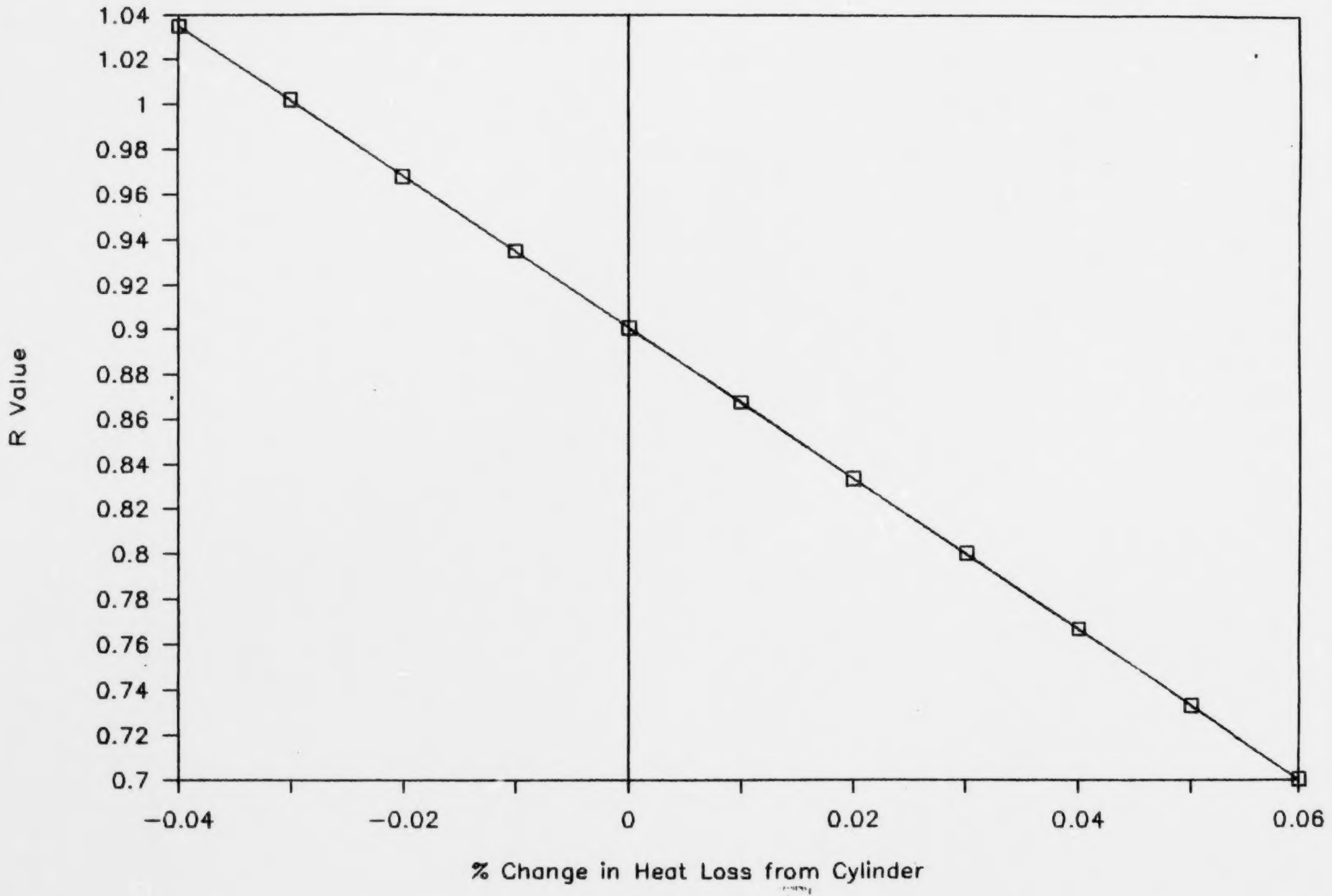

Sensitivity to F/A Ratio
decreasing heat of combustion /lb. fuel
Change in R
11
10
9
8
7
6
5
4
3
2
1
0
Q_c = -10 Btu
Q_c = -100 Btu
0.0001
0.0005
0.001
Change in F/A ratio

Figure 5-5

Sensitivity of R to Heat Loss Estimate



In summary, out of all of the possible reasons provided for a reduction in the value of R, only five of them are expected to have any effect at all, and of these, one can be expected to actually increase the value of R. The first point, higher cylinder temperatures due to the fuel property changes associated with RVP control was shown to result in a value of R of approximately 0.931. This value, however, was decreased by inclusion into the calculations of idle operation and engine friction resulting in a final R value estimate of 0.82. The fourth point, an increase in the F/A ratio tends to increase the value of R and has already been included throughout the calculations. The only point not included in the calculation was point 2; cold start open-loop operation. This can be expected to decrease the value of R, but since the effect of idle has probably already under estimated the value of R, the best assumption with the current information is to let the R value remain at the calculated level of 0.82.

To qualify this R value, it should be noted that it is based on a change in fuel properties which results from a change in fuel RVP. There are many other ways in which the fuel can be modified, with the expected changes in fuel properties different in each situation. For example, a change in the aromatic concentration of the fuel with little change in the butane concentration may result in vastly different specific gravity or F/A ratio changes for the resulting change in heat of combustion. As a result, the R values calculated may also prove different. The numbers shown above are only for the case of RVP control.

In addition to those already discussed, there is one more point which may increase the value of R. Since manufacturers currently optimize their engines on indolene test fuel rather than the actual in-use commercial fuel, in order to maximize the estimated corporate average fuel economy, there is gain to be made by having the in-use fuel be closer to the fuel for which the vehicles are optimized. However, again, no quantitative estimate can be made for this effect.

In an effort to support the modeling performed, the results from using the model on propane were compared with those from in-use information. However, the use of propane in the model requires an additional slight modification. Since the heat of combustion of propane per gallon of fuel is so much less than that of gasoline, it was assumed that a larger energy load on the fuel pump inversely proportional to the decrease in heat of combustion would be required to deliver an adequate amount of fuel to the engine. The fuel pump requires at most 0.25 HP or approximately 0.25 percent of the power output of a typical engine which is approximately .0625 percent of the energy input to the engine. Therefore, equation 5 becomes

$$6)\quad Q_2 = Q_2(.62)\left(\frac{Q_{cy12}}{Q_{cy11}}\right) + Q_1(.13)\left(\frac{Q_{f1}+F_1+Q_{cy12}}{Q_{f2}+F_2+Q_{cy11}}\right)$$

$$+ Q_1(.04)\left(\frac{Q_{c2}}{Q_{c1}}\right) + Q_1(.000625)\left(\frac{Q_{c2}}{Q_{c1}}\right) + 0.209375\ Q_1$$

The effect of this change to the model is small even with such a large change in fuel heat of combustion. Using values for propane versus 9.0 RVP gasoline in the model now results in an R value of 0.862. From actual vehicle data on propane fuel[19] the average increase in vehicle energy efficiency relative to gasoline is 4.82 percent. This increase in efficiency, when put into the following equation with the corresponding fuel properties results in an R value of 0.865.

$$7)\quad R = \frac{\%\ \Delta\ W}{\%\ \Delta\ Q_c}$$

where: $W = Q_c \times \text{eff}$

eff= energy efficiency of the engine

Although the possible errors in both the model and the data are significant, the remarkable correlation does serve to support the use of the model in other applications.

Like propane, methanol is also a fuel for which there is a relatively large amount of in-use data. When methanol is burned in a gasoline engine without making any significant design changes, the efficiency of the engine tends to improve by approximately five percent. This efficiency increase when combined with the fuel properties as shown in Table 5-16 results in an R value from equation 7 of 0.95 when compared with 9.0 RVP gasoline.

Since methanol is not a petroleum fuel, its application to volatility control may be questionable. However, since it is a pure compound, its properties are well known. In addition, since a comparison between gasoline and methanol involves large differences in fuel properties, the magnitude of the differences is statistically significant. Therefore, an R-value of 0.95 should represent a reasonable maximum value while the theoretically calculated 0.82 value is kept as a reasonable minimum value. Until such time as better fuels data is available, or better test data is available, the best estimate for the R value should be approximately 0.82 to 0.95.

4. R Value as it Relates to Evaporative Purge

In addition to the R value associated with the change in fuel properties. There is an R value associated with the efficiency at which a vehicle can burn the fuel-air mixture which results during purging of the evaporative canister. From data projected for the difference between controlled and uncontrolled evaporative emissions using 11.5 RVP fuel for the vehicle fleet in 1990, the amount of hydrocarbon trapped by the average evaporative canister is 47.685 grams per gallon of fuel during normal operation. Over the LA-4, it is estimated in Section I of Chapter 4 that the vehicle is able to purge the canister for slightly more than half of its driving time. If we assume then that the 47.685 grams of hydrocarbon is now only purged over half the time, and further, for a somewhat worse case, assume that it is all butane, then 4.317 liquid volume percent of the hydrocarbon entering the engine during purge is butane. Using a rule of thumb that 1.8 volume percent butane represents a change of 1 psi in RVP, during purge the engine is essentially burning a fuel with an RVP of 13.9, and approximately an 11 RVP fuel the rest of the time. The fuel properties for the 11 RVP and 13.9 RVP purge case are shown in Table 5-16. By applying these fuel parameters to the same models, equations, and conditions as previously yields an R value for this case of 0.831. In this instance, this means that the 0.71 percent drop in volumetric heat of combustion of the fuel during purge decreases fuel economy by only 83.1 percent of this amount. This of course assumes that the vehicle is able to maintain stoichiometry during purge, which was established in Section I of Chapter 4.

The purged hydrocarbon is entirely a benefit to fuel economy. Previously, the vapors merely escaped into the atmosphere and remained unburned. With the canister, the vapors are now consumed, but due to the carbon balance measurement of fuel economy, the benefit to fuel economy measured over the EPA test procedure goes unnoticed. However, using the R value calculated above, the relative efficiency of the burning of this purged hydrocarbon in the engine can be determined. Assuming as before that it is all butane, and that stoichiometry is maintained during purge, the relative efficiency of butane to gasoline is 1.0334. Thus, not only is there a benefit to actual fuel economy from the purged vapors, but there is the added benefit that they actually burn more efficiently than the gasoline coming from the fuel tank. Applying the estimated range for the value of R results in a corresponding range of 1.00976 at R = 0.95 to 1.03492 at R = 0.82 for the relative combustion efficiency of purged butane to that of gasoline.

C. Overall Relationship Between Gasoline Volatility and Fuel Economy

Combining the relationship between fuel volatility and energy density (from the Bonner and Moore study) with our best estimate for the relationship between energy density and fuel economy yields the overall relationship between fuel volatility and fuel economy. Energy density is projected to increase 0.25 percent with a 1-psi reduction in RVP and 0.56 percent with a 2-psi reduction in RVP. Vehicles should take advantage of this increase in energy density to achieve a resultant increase in fuel economy. Thus, for both feedback and non-feedback equipped vehicles, the increase in fuel economy for 1- and 2-psi reductions in RVP would be 0.205 to 0.238 and 0.459 to 0.532 percent, respectively. The fuel economy effects for other RVP reductions were derived by fitting a curve through these fuel economy increase values for 1- and 2-psi RVP reductions and are shown in Table 5-19.

These fuel economy increases were used to evaluate a dollar credit resulting from gasoline RVP control. This credit was determined by multiplying the percent increase in fuel economy by the total number of gallons of gasoline consumed by motor vehicles, and then valuing that gasoline at $0.82 per gallon. This value was determined by subtracting a consumption-weighted state fuel tax of $0.13 per gallon and the Federal tax of $0.09 per gallon from the 1984 national-average retail gasoline price of $1.04 per gallon.[20] In other words, the consumer would be able to travel additional miles on the high energy, low RVP gasoline, and is thus credited the dollar value of the gasoline he would otherwise have had to purchase in order to travel those extra miles made available by the resulting higher vehicular fuel economy.

D. Economic Credit From Evaporative HC Recovery/Prevention

There are three major sources of evaporative hydrocarbon emissions that are associated with gasoline RVP. They are losses from the gasoline distribution system (such as bulk storage terminal breathing losses, bulk transfer losses, and service station losses from transfer and underground tank breathing), refueling emissions, and motor vehicle evaporative emissions. The emission reductions for each of these sources associated with RVP control are detailed in Chapter 3 of this study. However, in addition to representing an environmental benefit, these emission reductions also represent an economic benefit in that these HC emissions are now available to be consumed as fuel by the motor vehicle (i.e., current emissions due to high volatility fuel represent a cost to the economy). The same is true for certification fuel RVP control, although only evaporative emission reductions from motor vehicles are relevant there. The methodology used to evaluate this cost credit resulting from the recovery and prevention of evaporative HC emissions via both fuel and vehicle control is outlined below.

The reductions in evaporative HC emissions from the distribution system, refueling, and motor vehicles (as described in Chapter 5) are used directly to determine the mass of HC now usable that would otherwise be lost if excess evaporative emissions were not controlled. This tonnage of hydrocarbons is converted to an equivalent volume using the

Table 5-19

Fuel Economy Effect of RVP Control

RVP Reduction (psi)	Percent Increase in Fuel Economy	
	Best Estimate R = 0.82	R=0.95
0.5	0.090	0.105
1.0	0.205	0.238
1.5	0.328	0.380
2.0	0.459	0.532
2.5	0.599	0.694
3.0	0.741	0.859
3.5	0.890	1.031

density (lb/gal) of the hydrocarbons. Because the lighter hydrocarbons evaporate first, the specific gravity and energy densities (Btu/gal) of those hydrocarbons no longer lost to evaporation are significantly less than those of gasoline. As a first-order estimate, the evaporative hydrocarbons were all assumed to be butanes. The equivalent volume (gallons) of butane saved by RVP reduction is converted to energy using butane's energy content. This energy is then converted to equivalent gallons of gasoline, using a representative gasoline energy content figure (Btu/gallon). This volume of gasoline is then converted to a dollar amount using a value of $0.82 per gallon of gasoline for the $20/bbl case. Overall, the value of a ton of evaporative emissions (butane) controlled or prevented is $290.32. The value of a gallon of gasoline needed to be determined as a function of crude oil price. Data was collected from Oil and Gas Journal from September of 1985 to September of 1986 in order to draw a correlation between gasoline price and crude oil price. The retail price of gasoline (minus taxes) was found to be strongly correlated to crude oil price if a 2 week lag period between the crude oil price and the pump price was assumed (R=0.94). The results of the correlation for the range of crude prices examined in this study, as well as the estimates for densities, energy densities, and gasoline value are summarized in Table 5-20.

VI. Effect of RVP Control on Driveability

This section presents an analysis of the effects of reducing the volatility of gasoline on vehicle driveability. In the period from 1974 to 1985 the volatility of unleaded regular gasoline as measured by the Reid Vapor Pressure (RVP) increased by 10 percent to 20 percent depending on the area of the country (see Table 5-21, Figure 5-6). In 1985 for the first time the average level of volatility surpassed the average ASTM recommended limit with a level of 10.8 psi RVP and maximum levels as high as 13.6 psi RVP. The increase for alcohol-containing unleaded regular gasoline has been even greater with average levels reaching 11.5 psi RVP and maximums as high as 14.0 psi RVP. Although during the same period vehicles have been designed to run satisfactorily on higher volatility fuels, there is evidence which suggests that the current fuel volatility has increased beyond the design point of many vehicles in service. Some vehicles experience varying levels of vapor lock and fuel foaming, both of which are caused by high volatility, and both of which cause vehicle surge, hesitation, power sags, engine stalling, and difficulty or failure to start. This poor engine performance in turn results in a severe increase in vehicle exhaust emissions. For these reasons there is an immediate benefit to the auto manufacturer, the consumer and to the environment to be realized through better engine performance by reducing the volatility of the fuel.

Table 5-20

Estimates for Evaluating the Evaporative Recovery/ Prevention Credit Resulting from RVP Control

Description	Units	Estimate
Composition of Evap. Emissions		100% Butane
Density of Butane	lb/gal	4.77
Energy Density of Butane	Btu/lb Btu/gal	19,500 93,100
Energy Density of Gasoline	Btu/lb Btu/gal	18,500 114,000
Value of Gasoline	$/gal $/gal $/gal	0.90 ($25/bbl crude) 0.82 ($20/bbl crude) 0.73 ($15/bbl crude)
Value of Controlled/Prevented		
Evap. Emissions (Butane)	$/ton	290.32 ($20/bbl crude)

Table 5-21

NIPER Survey Results[22]: Summer Gasoline RVP Trends by Region*

Region	Years												% Increase over 11 yrs.	Avg ASTM Limit
	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985		
Northeast	9.8	10.0	10.2	10.7	10.5	10.5	10.8	10.8	10.9	10.5	10.7	11.2	14	11.5
Mid-Atlantic Coast	9.3	10.1	10.1	10.4	10.1	10.2	10.3	10.6	10.8	10.7	10.8	11.1	19	11.5
Southeast	9.6	9.6	9.7	9.5	9.4	9.6	9.8	9.9	10.1	10.3	10.2	10.6	10	11.0
Appalachian	10.5	10.6	10.5	10.4	10.1	10.6	10.5	10.9	11.1	11.4	11.1	11.5	10	11.5
Michigan	10.5	10.4	10.6	11.0	11.2	10.9	11.3	10.9	11.2	11.6	11.5	11.8	12	11.5
Northern Illinois	9.5	10.5	10.3	11.0	10.8	10.9	10.9	11.1	10.8	11.7	11.3	11.2	18	11.5
Central Mississippi	10.1	10.1	9.9	9.9	10.1	10.4	10.3	9.7	10.5	11.0	10.9	11.1	10	11.0
Lower Mississippi	9.4	9.6	9.6	9.5	9.8	9.5	9.7	9.3	10.1	10.1	10.0	10.5	12	10.5
Northern Plains	--	9.6	9.9	--	--	9.2	9.8	--	11.0	11.0	10.5	11.3	18	10.5
Central Plains	--	9.1	9.2	9.0	8.8	9.2	9.2	--	10.2	10.0	10.0	10.3	13	10.0
Southern Plains	9.2	9.3	9.2	9.3	9.1	9.5	9.2	9.7	10.0	9.8	9.8	10.1	10	10.0
Southern Texas	9.1	9.5	9.4	9.6	9.5	9.4	9.2	9.4	10.3	10.2	10.3	10.1	11	9.5
Southern Mountain	8.4	8.9	8.7	8.8	8.9	8.7	8.9	8.4	8.8	9.1	8.9	9.4	12	9.5
Northern Mountain	8.9	10.1	9.5	9.9	9.9	9.6	9.5	9.2	10.4	10.4	9.7	10.4	17	10.0
Pacific Northwest	9.5	9.9	10.6	10.4	10.0	10.3	10.8	11.0	10.8	11.2	10.8	11.4	20	11.0
National Average** (excluding California)	9.5	9.8	9.8	10.0	9.9	9.2	10.0	10.1	10.5	10.6	10.4	10.8	14	10.7

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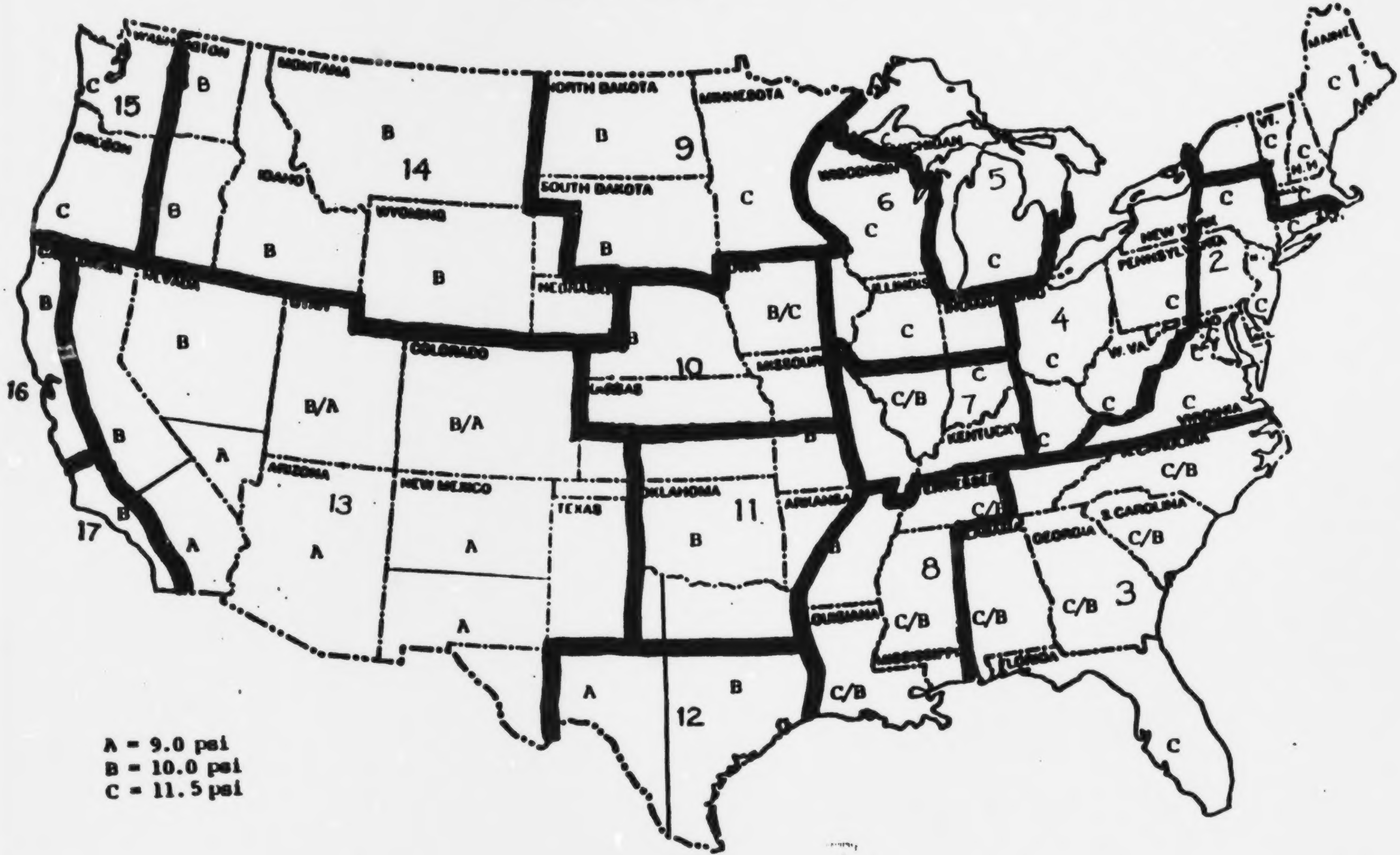
* Unleaded regular gasoline only (R + M/2 less than 90).

** Calculated as a straight arithmetic average of the 15 regional averages listed.

Figure 5-6

NIPER Survey Regions and

ASTM's July Volatility Classes


WASHINGTON
OREGON
IDAHO
MONTANA
WYOMING
NEVADA
UTAH
COLORADO
ARIZONA
NEW MEXICO
NORTH DAKOTA
SOUTH DAKOTA
NEBRASKA
KANSAS
OKLAHOMA
TEXAS
MINNESOTA
IOWA
MISSOURI
ARKANSAS
LOUISIANA
WISCONSIN
MICHIGAN
ILLINOIS
INDIANA
OHIO
KENTUCKY
TENNESSEE
MISSISSIPPI
ALABAMA
GEORGIA
FLORIDA
S.CAROLINA
N.CAROLINA
VIRGINIA
W.VA
PENNSYLVANIA
NEW YORK
VT.
N.H.
MAINE
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
A = 9.0 psi
B = 10.0 psi
C = 11.5 psi

A. Studies Performed on the Subject of Driveability

Vehicle driveability as discussed here is a function of vehicle design, fuel characteristics, ambient conditions, and characteristics of operation. Thus, there is a broad range of possible situations during which a vehicle will experience driveability problems. For our purposes these many different situations are reduced to some extent by the fact that volatility will only be controlled during the summer months, so cold temperature driveability problems are of less concern. But of interest is the entire range of vehicles on the road today. The fact that current model year vehicles may be able to run on high volatility fuel does not allow volatility to be increased to a level where past model year vehicles encounter difficulties.

One study on this subject performed by the Coordinated Research Council (CRC)[23] consisted of tests using incremental RVP blends of two fuels on twelve 1971 model year vehicles. This testing was conducted at 95°F ambient temperatures and relatively low altitude. The results show that on the average the vehicles began to experience vapor lock limited performance at approximately 9.5 psi RVP. In addition, the average RVP at which the vehicles began to experience significant driveaway driveability demerit levels (Demerits are given for any driveability problems such as stumble, hesitation, or surge during vehicle operation by trained observers. The amount of demerits given is consistent with the magnitude of the problem.) was 9.8 psi. Vehicle to vehicle variability was very high as would be expected with vehicles of different design, but the general trend holds true, that driveability worsened at increasing volatility levels.

In a second CRC study[24] more recent vehicles were used to once again determine driveability and vapor lock limited performance. This time 47 1977-81 model year vehicles were tested, and 32 of these experienced vapor lock limited performance over the range of fuel volatilities tested at the 100°F ambient test condition. The average fuel RVP at which these vehicles experienced vapor lock symptoms was approximately 9.35 psi, and of those which did not encounter vapor lock, the average maximum fuel RVP level tested was 11.7 psi.

As another measure of driveability, a hot start and driveaway evaluation of driveability on the 47 vehicles adjusted for rater severity and for $T_{v/L=20}$ adjusted for an ambient temperature of 100°F was performed. This showed that the total weighted demerits (TWD) associated with driveability problems increased using a geometric mean from 24.4 TWD with the low 7.3 RVP fuel to 38.9 TWD with the midrange 10.6 RVP fuel to 53.8 TWD with the high 14.2 RVP fuel.

In still another measure of driveability in this study, the customer responses for acceptability and overall performance of their vehicle with the various fuels provided showed that for fuels with RVP greater than 13.7, 23 percent of the total number of days driven were reported as being unacceptable. This total drops to 9.9 percent for fuels with approximately an 11.5 RVP, 6.2 percent at 10.0 psi RVP, 3.2 percent at 8 psi RVP, and down to zero at approximately 7.0 psi RVP. However, at 6.2 psi the percentage of days reported as unacceptable increases to 16.7 percent probably due to cold start problems in early morning. Ambient information throughout the period of these evaluations showed an average daily low temperature of 83.4°F and an average daily high temperature of 106°F. These averages correspond to a temperature range of 70°F to 114°F during the months of June through August in Phoenix, Arizona.

Data on vapor lock limited performance from the two CRC studies just discussed as well as two other CRC studies are shown in Figure 5-6. It shows that for 1971, 1975, 1977-81, and 1982 model year vehicles to achieve a 90 percent customer driveability performance satisfaction level, fuel volatility levels of 5.0, 7.1, 7.6, and 10.0 psi RVP are required respectively. Thus, these data seem to support the contention that as fuel volatility has been increasing, the ability of vehicles to perform on higher volatility fuels has also been increasing. But in the last few years the fuel volatility seems to have surpassed that for which all vehicles can function properly.

Fuel-injected (FI) vehicles seem to be better able to handle higher volatility fuels whereas carbureted vehicles have more difficulty. This can be seen in data collected from a study of three carbureted and three FI 1983-4 vehicles.[25] Testing conducted at 80 to 90°F showed that the carbureted vehicles experience approximately twice as many driveability demerits as the FI vehicles. In addition, the carbureted vehicles were much more sensitive to fuel volatility than the FI vehicles. The driveability demerits for the FI vehicles remained relatively constant between ASTM class D (13.6 RVP avg) and class C (11.6 RVP avg) fuels tested whereas the demerits for the carbureted vehicle increased on the average by 50 percent.

One explanation for the poorer performance of carbureted vehicles over and above that of FI vehicles is the emergence of an additional driveability problem, this being fuel foaming in the carburetor. Fuel foaming occurs when foam forms in the carburetor bowl causing the float to fall below its normal level and allowing fuel to continue to flow. Although the symptoms such as stumble, surge, poor idling and acceleration and even stalling are the same as for vapor lock, they are caused by enrichening of the A/F mixture rather than the leaning of it. In addition, one of the best solutions for vapor lock; putting an electric fuel pump in the fuel tank which pressurizes the entire fuel system; actually causes more fuel foaming in carbureted vehicles. One study[26] done on just a single 1981 carbureted vehicle showed that at 68°F ambient temperatures, a fuel with an RVP of 17.5 psi was required before fuel foaming became significant enough to limit vehicle performance. However, at 86°F the limiting RVP was reduced to 13.5 psi, and at 104°F ambient temperatures, a fuel with an RVP of 11.4 psi provided critical performance. Thus, based on this data alone, it is possible that vehicles on the road at today's fuel volatilities could experience fuel foaming limited performance.

All of the information seen thus far seems to suggest that the current level of fuel volatility is too high for the broad range of vehicle designs on the market to operate acceptably. This in turn suggests that there may be some benefit in reducing the volatility of the fuel from a driveability point of view. However, care must be taken not to decrease the volatility too far, for just as there are driveability problems with fuel of too high a volatility, there has also been data shown to suggest driveability problems even in the Desert Southwest when volatility falls to the extremes of 6.2 psi RVP.

For the most part, the level of volatility control proposed in this study will not interfere with cold temperature driveability. Only May through September volatility control is being proposed, so in most cases the temperatures and proposed volatility levels are high enough to circumvent any problems. Under the 9 psi Class C RVP scenario, a 22 percent reduction from current ASTM classifications results in a fuel RVP of 7.0, 8.0 and 9.0 psi for Class A, B and C areas, respectively. The fact that this volatility level is adequate for driveability is substantiated by the fact that California, which has had volatility control to 9.0 psi during the months of April through October in effect since 1971, has not had any low temperature driveability problems recorded.[27] This despite the fact that the South Coast air basin is ASTM Class C in April and B/C in October. Even with the 9 lb. control, a check of fuel in in-use vehicles found that the RVP of the gasoline is typically 8.5 psi, and often as low as 8.0 psi, though weathering may account for some of the difference. In addition, often vehicles fueled on this low volatility fuel travel into the mountains where 10th percentile minimum temperatures are in the low to mid 30's. These temperatures correspond to the lowest of the 10th percentile minimum temperatures for the majority of the nation during the summer months. Therefore, reducing the nations fuel volatility by 22 percent would not appear to cause any problems based on the real world information from California.

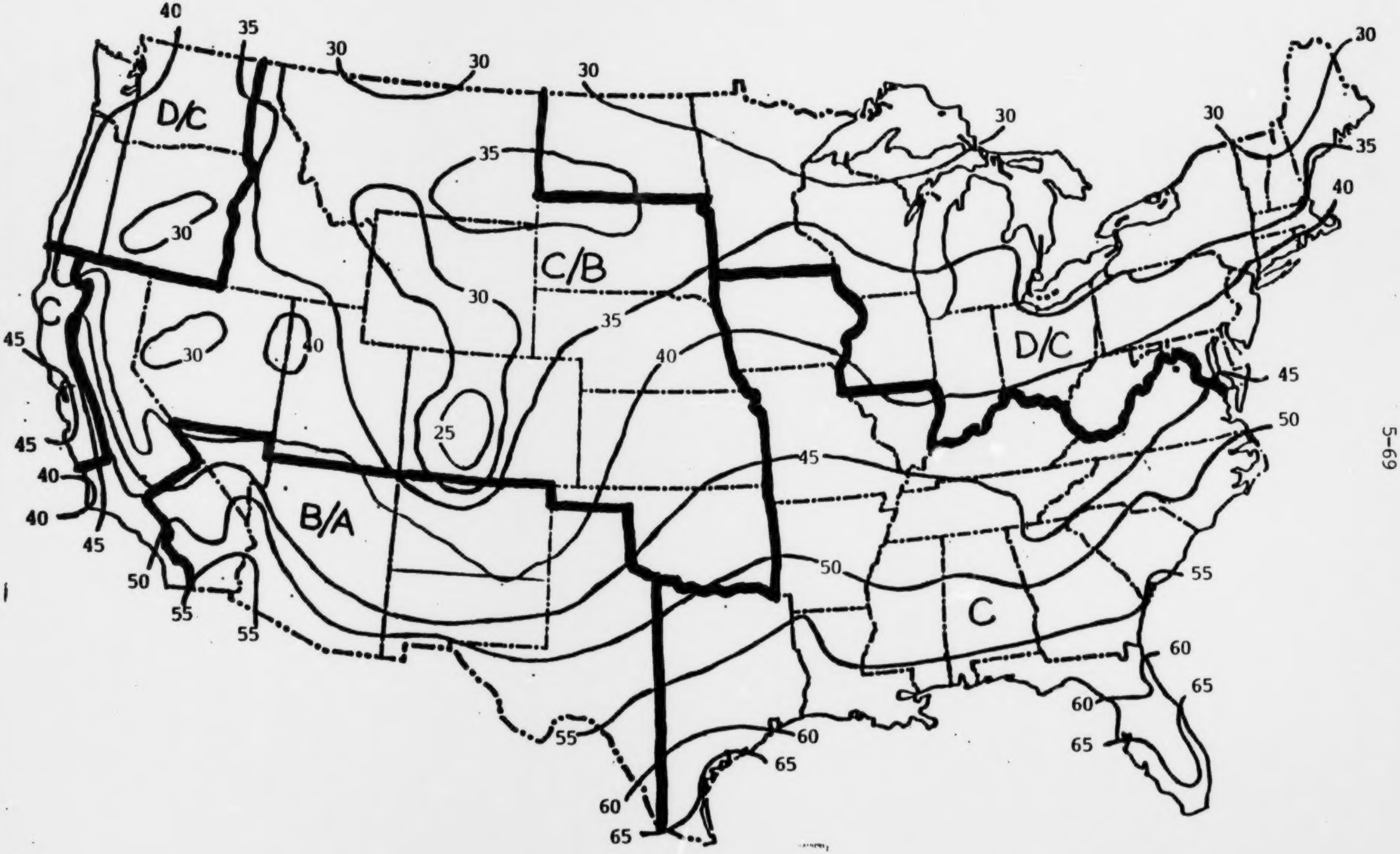
The 8 psi Class C RVP scenario, in which there are fuel RVP reductions of 30 percent, would reduce fuel RVP in Class A areas to 6.3 psi. Control to this extreme as mentioned earlier with respect to a CRC study[24] may be too low for some vehicles to operate satisfactorily.

Another study presented in the comments by API[28] also suggests that some concern may be warranted with 30, or possibly even 22 percent control. In this study Chevron tested 8 1973-76 model year vehicles with fuels of 8.5 and 6.5 RVP at 75°F and 55°F ambient temperatures. 55°F was chosen to be representative of typical morning temperatures in the LA Basin based on April through October data of average daily lows. Results of the testing indicate that due to the reduction in volatility from 8.5 psi to 6.5 psi, driveability demerits increased by 123 percent and 252 percent at 75°F and 55°F, respectively. Also, driveability demerits increased by 19 and 87 percent at 8.5 psi and 6.5 psi, respectively, due to the reduction in temperature from 75°F to 55°F. Thus, this study although on older vehicles suggests that the 30 percent and possibly 22 percent reduction in volatility is too severe, especially as it relates to class A regions.

Another study by CRC on customer evaluations of cold temperature driveability found similar, but not quite so drastic results.[29] They tested 107 1973-78 vehicles with fuels of 7.6, 10.1, and 12.7 psi RVP in San Antonio Texas from January 23 to April 3. The 10th percentile minimum temperature for this period in San Antonio is approximately 35°F corresponding to the minimum for the B/A ASTM classification regions in May (see Figure 5-7) or the Class B regions in June (see Figure 3). The results indicated that although the 10.1 psi fuel achieved nearly the same level of satisfaction as the 12.7 psi fuel (87 and 93 percent respectively) the 7.6 psi fuel merely achieved a 62 percent level of satisfaction. This suggests that based on temperature and gasoline volatility data for the country,[30] as seen in Figures 5-7 through 5-9, even with the 22 percent RVP reduction (7.8 psi in Class B), there are certain areas of the country in early May, early June, or late September such as the high mountain areas of the west, or extreme northern plain states where some vehicles may encounter cold temperature driveability problems.

One must be careful, however, when drawing any definite conclusions from these studies since many of the areas with the lowest temperatures are also the areas with the highest altitude. The required fuel volatility for starting and operating a vehicle under cold conditions is dependent upon achieving a minimum combustible air-fuel ratio. As one increases in altitude from sea level to 13,000 feet, the air density decreases by 2.9 to 2.2 percent per thousand feet. Thus, it becomes easier and easier to achieve this air-fuel ratio. This in turn means that as one increases in altitude, a lower and lower volatility fuel (at constant temperature) is acceptable for cold temperature operation. Since the altitude

Figure 5-7
Nationwide 10th Percentile Minimum Tempuratures
for May with Corresponding ASTM Classifications


40
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D/C
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D/C
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B/A
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C
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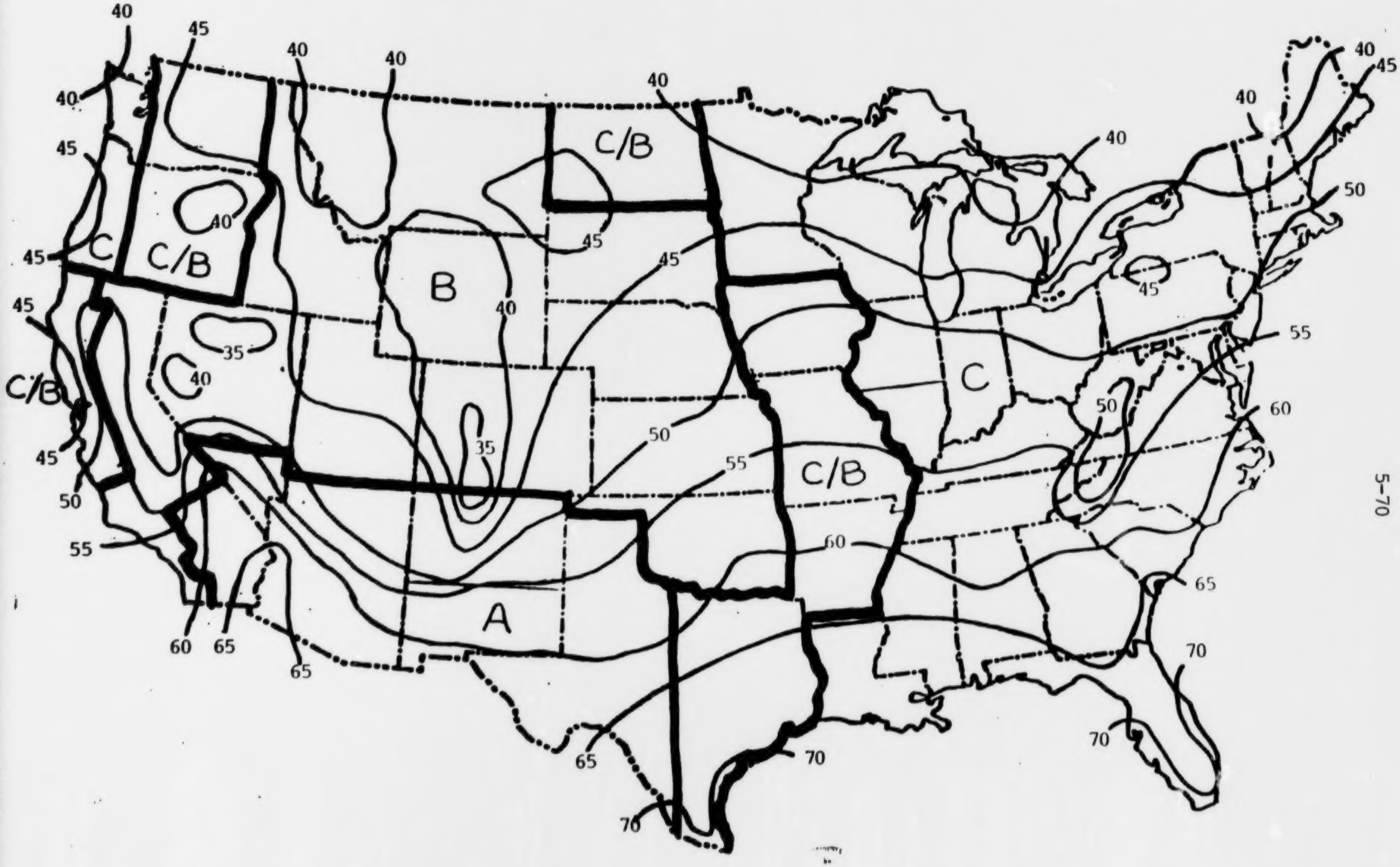
Figure 5-8
Nationwide 10th Percentile Minimum Temperatures
For June with Corresponding ASTM Classifications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C
C/B
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C/B
45
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40
C/B
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50
55
C
55
C/B
60
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60
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A
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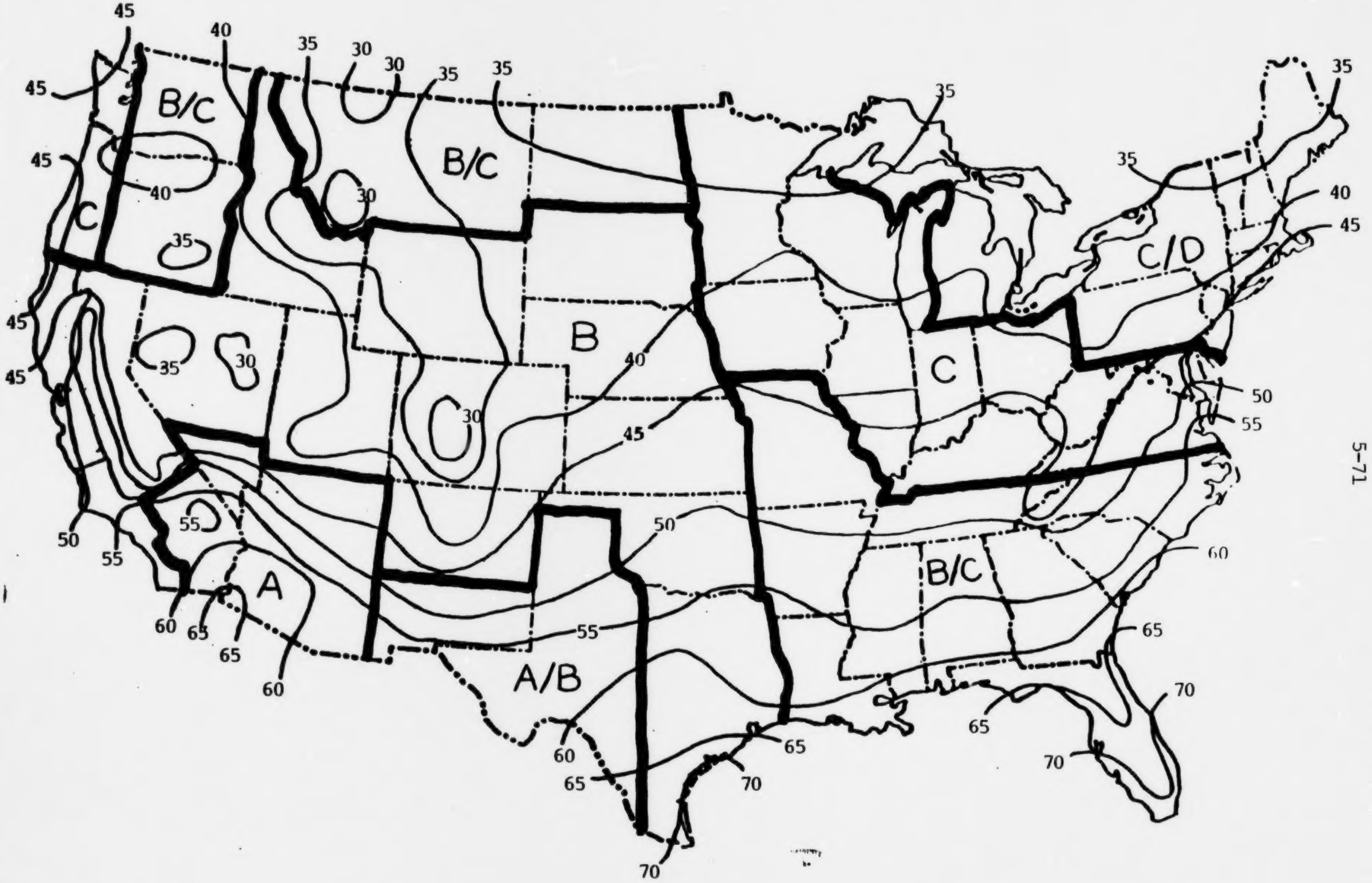
Figure 5-9
Nationwide 10th Percentile Minimum Temperatures
For September with Corresponding ASTM Classifications


B/C
C
B/C
B
C
C/D
B/C
A
A/B
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of San Antonio, Texas is only 701 feet, the driveability results with the 10.1 psi fuel tested would correspond with those from testing an 8.8 psi fuel in Denver, Colorado or a 9.4 psi fuel in Great Falls, Montana. The results with the 7.6 psi fuel in turn, would be similar to those from testing a 6.6 psi fuel in Denver, or a 7.0 psi fuel in Great Falls. Thus, although the first glance might suggest the contrary, from a closer look, a 22 percent reduction from current ASTM may not cause any significant driveability problems in the United States. In addition, all of the data available on cold temperature low volatility driveability was for vehicles of 1978 or earlier model years. Thus, the improvements in recent years for vehicles to operate better on a wider range of A/F ratios is not expressed in any of the information with the exception of the comments from California which suggest no concern may be warranted for a fuel with a 22 percent reduction in volatility from current ASTM classifications.

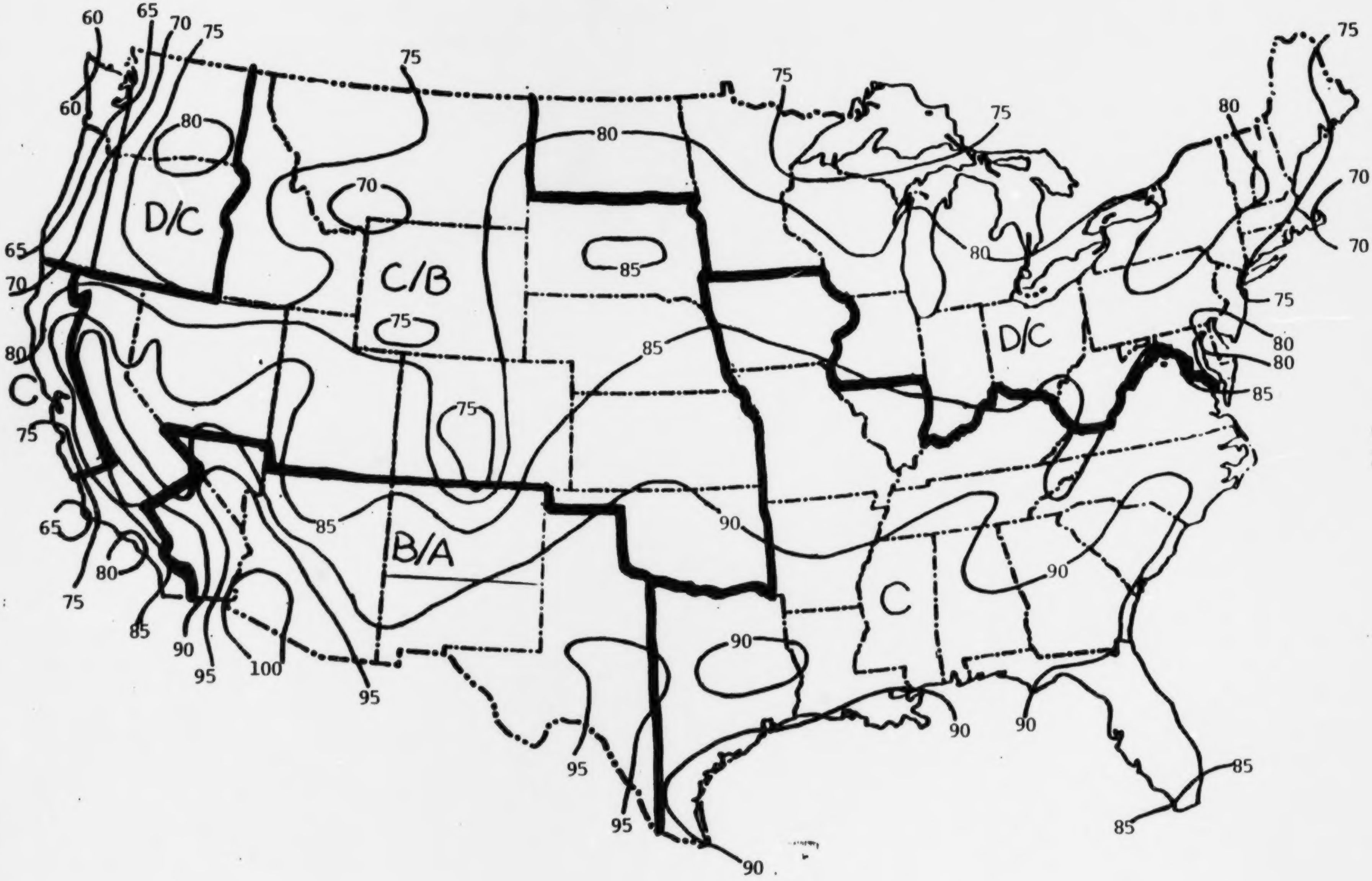
As one final point, although the 10th percentile minimum temperatures for these regions may be low enough to be of concern, lacking more recent and extensive information, the same regions have 90th percentile maximum temperatures during the same periods which become of concern under high temperature driveability situations (see Figures 5-10 through 5-12). Thus, although there may be some possibility of low temperature driveability problems during the volatility control season, the reduction in high temperature driveability problems should far outweigh them.

B. Industry Data on Current Volatility Related Problems

In their comments to us, GM and Chrysler provided information on vehicles which have experienced warranty problems due to fuel volatility increases. Ford, although insisting that they too were experiencing many of the same problems and costs associated with fuel volatility, declined to provide any information. Nissan was the only other manufacturer to make any comment on this topic, and although not providing any information on warranty problems, did say that rising volatility had forced them to adapt their vehicles to avoid driveability problems by designing them with injector blowers, fuel temperature sensors, and fuel pressure control systems.[31]

In the case of GM, there are three different vehicle lines of 1982 and 1985 model year which experience vapor lock problems during hot summer conditions throughout the country.[32] GM estimates that, of the 570,000 of these vehicles built, more than 10,000 annually experience this problem nationwide. The simplest and most effective solution is to install a small fan for improved cooling of the carburetor. Another effective solution, but one which is considerably more involved, is to replace the existing fuel pump with an improved electric, in-tank fuel pump.

Figure 5-10
Nationwide 90th Percentile Maximum Temperatures
For May with Corresponding ASTM Classifications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C/B
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B/A
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D/C
C
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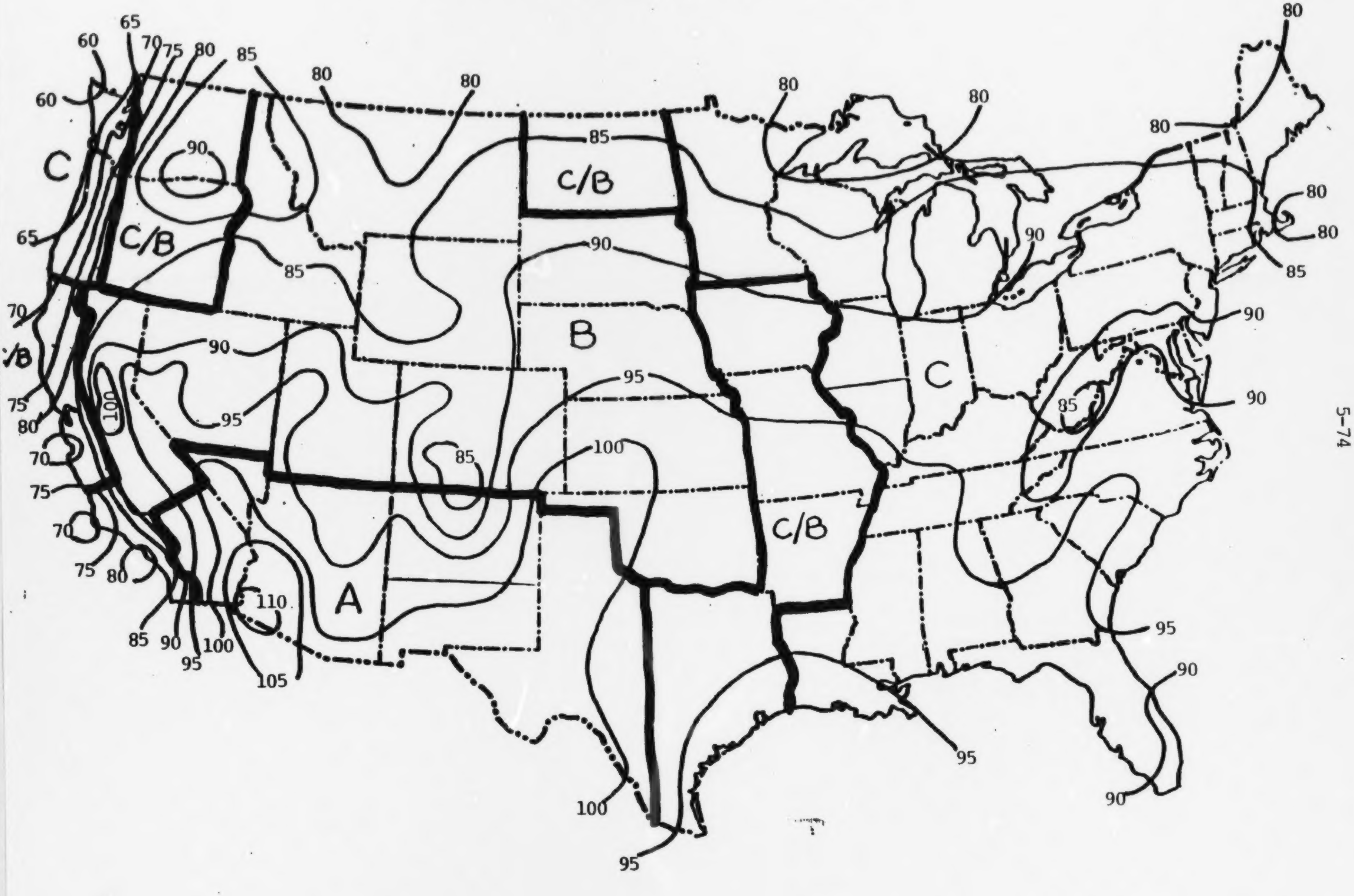
Figure 5-11
Nationwide 90th Percentile Maximum Temperatures
For June with Corresponding ASTM Classifications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C/B
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C/B
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85
65
70
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C
/B
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100
85
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85
70
100
75
C/B
70
A
110
75
80
85
90
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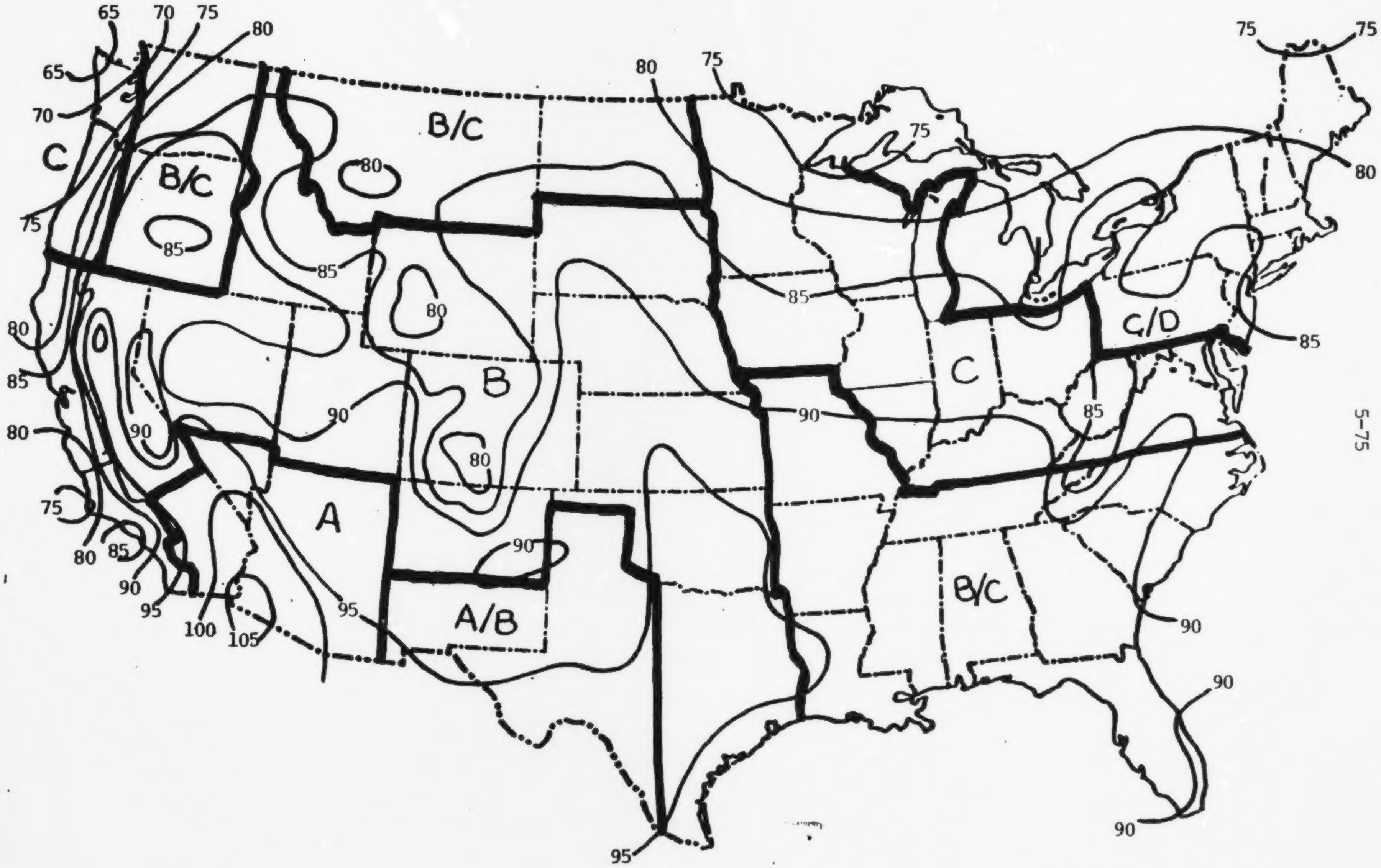
95

Figure 5-12
Nationwide 90th Percentile Maximum Temperatures
For September with Corresponding ASTM Classifications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A
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A/B
95
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105
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B/C
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75
75
80

In addition to those three vehicle lines, there are an additional 10 1982-5 model year vehicle lines which experience vapor lock problems under high altitude conditions. In this case GM estimates approximately 1500 vehicles annually experience this problem, and for these situations, the more tedious and costly fuel pump replacement seems to be the best solution.

One additional engine produced by GM has also been experiencing increased complaints. Unlike all the other vehicles which were carbureted, this is a 1981 6.0l throttle-body fuel-injected vehicle (TBI). The solution was to insulate the fuel lines, and to replace the gasket under the TBI unit with one with lower thermal conductivity.

Chrysler, as opposed to GM, seems to have a larger problem with driveability at today's volatility levels. They have at least 38 vehicle/engine combinations (25 different vehicle lines 13 of which have two different engine sizes) of 1981-1986 model year for which they have published Technical Service Bulletins.[33] Chrysler sites fuel foaming, vapor lock, or both as the primary source of the problem in all instances. The most common solution to the problem is the installation of a new in-tank electric fuel pump, a pressure regulator control module and a fuel reservoir filter. In some instances an electric fan placed on the engine to cool the carburetor after the engine is turned off provided an acceptable solution. Unfortunately Chysler did not state a total vehicle population which has or is projected to be affected by these problems.

C. Costs Associated With High Volatility Driveability Problems

In order to accurately quantify the cost associated with high volatility driveability problems, there are many different second order costs to be taken into account due mainly to the costs incurred when vehicles breakdown. Unfortunately most of these costs are not easily quantifiable. However, two first-order costs to the manufacturer; warranty costs, and required vehicle design modification costs, can be quantified to some extent.

In the case of Chrysler, they have estimated that through approximately February 1986 they have paid out over $14 million in volatility-related warranty costs. These costs have been incurred mainly since 1981 when volatility began to reach levels of concern in some areas of the country. In addition, the only available information suggests that only 1981 and later Chrysler vehicles have routinely received warranty fixes.

The most common warranty fix in the case of Chrysler is the replacement of the current fuel pump with an in-tank electric fuel pump, and also the installation of a pressure regulator in the fuel line. These parts and associated hardware as well as labor, cost Chrysler an estimated $400 per warranty fix. Thus, over the five year period since 1981, Chrysler has had approximately 7000 vehicles per year undergo such a warranty fix. When the warranty costs are averaged out over Chrysler's total U.S. new vehicle registration of 4,311,918 from 1981 through 1985, the average cost to Chrysler is $3.25 per vehicle registered in the U.S. due to volatility related problems.

In the case of GM, they estimate that approximately 11,500 vehicles per year undergo volatility related warranty fixes. Of these only approximately 1500 undergo the expensive fuel pump replacement whereas the other 10,000 undergo the less expensive installation of an after-run fan. Due to this, the estimated cost to GM per vehicle fix under warranty has only been approximately $130. This adds up to a cost to GM of approximately $7.5 million over the 1981-1985 period. This in turn breaks down to a per U.S. registered GM vehicle cost of approximately 40¢. This is much smaller than the cost to Chrysler due mainly to a much smaller fraction of vehicles with volatility related problems.

If we combine the warranty costs and total vehicle registration of both GM and Chrysler, the average cost per vehicle is 88¢. Since no other data was presented by industry, applying this cost to the total U.S. new vehicle registration over the last five years, the total warranty costs add up to $40.5 million, or an average cost per year of $8.1 million.

Chrysler was also the only manufacturer to provide any information on costs associated with vehicle design modification to correct problems associated with fuel volatility. Chrysler estimated that up until about February of 1986 they have spent upwards of $58 million in design changes. If once again we can assume that these costs have been incurred over the 1981 through 1985 model years, the average cost for such vehicle modifications is $13.5 per vehicle, which in turn adds up to a total nationwide cost of $124.1 million per year. Although it would be impossible to recover all of these costs if fuel volatility were reduced, Chrysler did state that a fuel temperature measurement device, and a fuel tank pressure relief valve could be removed from the vehicle at a retail cost savings of $11.29 per vehicle. Based on a contracted cost study conducted for EPA, the retail cost of these parts on a production vehicle, corrected for overhead and inflation, is approximately $4.76 per vehicle.[34] This is actually higher than might have been predicted by using a rule of thumb markup factor of 4.5 from factory retail costs to after market retail costs. If averaged over the total U.S. new vehicle registration, this becomes an annual cost of $44 million to the manufacturers. Additional savings could likely be realized as at lower volatility manufacturers would once again have greater flexibility in the design and manufacturing of the fuel systems.

The driveability cost estimates cited above are not based on hard evidence, but rather on the limited information provided by GM and Chrysler. Although the analysis was qualitatively believable, there exists no verifiable basis for relying on any precise estimates.

In addition to the direct cost savings presented, there are also many "intangible costs" associated with driveability problems which although difficult to quantify are never-the-less real. These costs include direct costs to the consumer for the reduction in fuel economy due to poor driveability, as well as indirect costs to society associated with the increase in emissions from poorly operating vehicles. In addition to these, Chrysler also mentioned some "intangible" costs associated with driveability problems due to high fuel volatility:

1) The costs of "substitute transportation" in the form of a towing fee and car rental and/or taxi costs when the vehicle stalls due to vapor lock or fuel foaming;

2) Payments to repair garages for attempted fixes when the problem is improperly diagnosed;

3) Higher prices on new cars due to manufacturer warranty costs on existing vehicles;

4) Costs associated with motorist insurance and auto club fees in case of vehicle breakdown;

5) Costs associated with the willingness of many people to pay from 1¢ to 3¢ extra per gallon for fuel which they know will give better performance;

6) Costs to motorists through taxes to support public agencies which must cope with vehicles which breakdown; and

7) Litigation costs involving product quality.

These "intangible" costs, although legitimate costs, are not all mutually exclusive of each other. Often "substitute transportation" is paid for by motorist's insurance and auto club memberships, and many of the payments to repair garages for improper fixes are covered under warranty costs. In addition, by paying 1¢ to 3¢ extra per gallon of fuel, those consumers avoid recurrence of driveability problems and the further costs associated with them. Thus, this cost may not really be intangible, but rather an alternative way to establish the total societal cost associated with driveability.

There was no actual data shown by Chrysler in support of the 1¢ to 3¢ price range. However, it seems reasonable that people who are experiencing driveability problems would be willing to pay extra per gallon for fuel on which their vehicle will perform better. AAA in their testimony at the hearing on the 1985 volatility study stated that people will willingly pay 1¢ to 3¢ extra per gallon. Chrysler appears to accept this testimony by using it in their comments. It also seems reasonable in light of the broad range of fuel prices at the retailers today which vary by as much as 10 cents per gallon, that 1¢ to 3¢ extra per gallon may be an accurate if not low estimate. If people whose vehicles are experiencing driveability problems are willing to spend extra per gallon of fuel, then combining this with the information shown in Figure 5-13 on the satisfaction of vehicle operation with fuels of varying volatility, a cost to the consumer can be determined. CRC stated that for an increase in the ambient temperature, there is a corresponding decrease in the temperature at which the vapor to liquid ratio equals 20. Therefore, the satisfaction of driveability of vehicles at a given ambient temperature can be determined by raising or lowering the vertical axis of Figure 5-13. Using Figure 5-13 and available ambient temperature data, the number of vehicles, and the age of those vehicles in a given area should enable the determination of the number of vehicles in that area which have unsatisfactory performance due to fuel volatility. Knowing the fuel consumption of these vehicles and the amount extra per gallon they are willing to pay now provides the total cost associated with driveability.

For the calculation, the temperature data for the summer months of April through October for the ten largest (non-California) ozone non-attainment cities in the U.S. (see Table 5-22) were chosen since it was readily available and fairly representative of the nation as a whole. The vehicle population for these cities was assumed to be proportional to population (see Table 5-22). The age of the vehicles was proportioned according to the MOBILE3 VMT mix for vehicles of various model years as seen in Table 5-23. As Figure 5-13 does not show a curve for each model year (MY), vehicles of 1971 through 1974 MY were assumed to correspond to the line labeled 1971 model cars, 1975-6 MY vehicles to the line labeled 1975, and all vehicles of 1982 and later MY to correspond to the line labeled 1982 model cars. Once the percentage of vehicles dissatisfied for these 10 cities was determined, the results were applied to the national fuel consumption data. Using the range of 1¢ to 3¢ per gallon that the people with driveability problems are willing to pay yields the cost savings associated with volatility control. These cost savings as seen in Table 5-24 are as high as $78.0 million dollars per year depending on the level of volatility control, the calendar year, and the amount extra per gallon that people are willing to pay.

Although certain assumptions such as lumping all of the 1982 and later vehicles into one group may tend to over-estimate these costs associated with driveability, the use

FIGURE 5-13

DISTRIBUTION OF VAPOR LOCK LIMITING $T_{V/L=20}$ AT 100°F AMBIENT IN FOUR CRC PROGRAMS[ ]

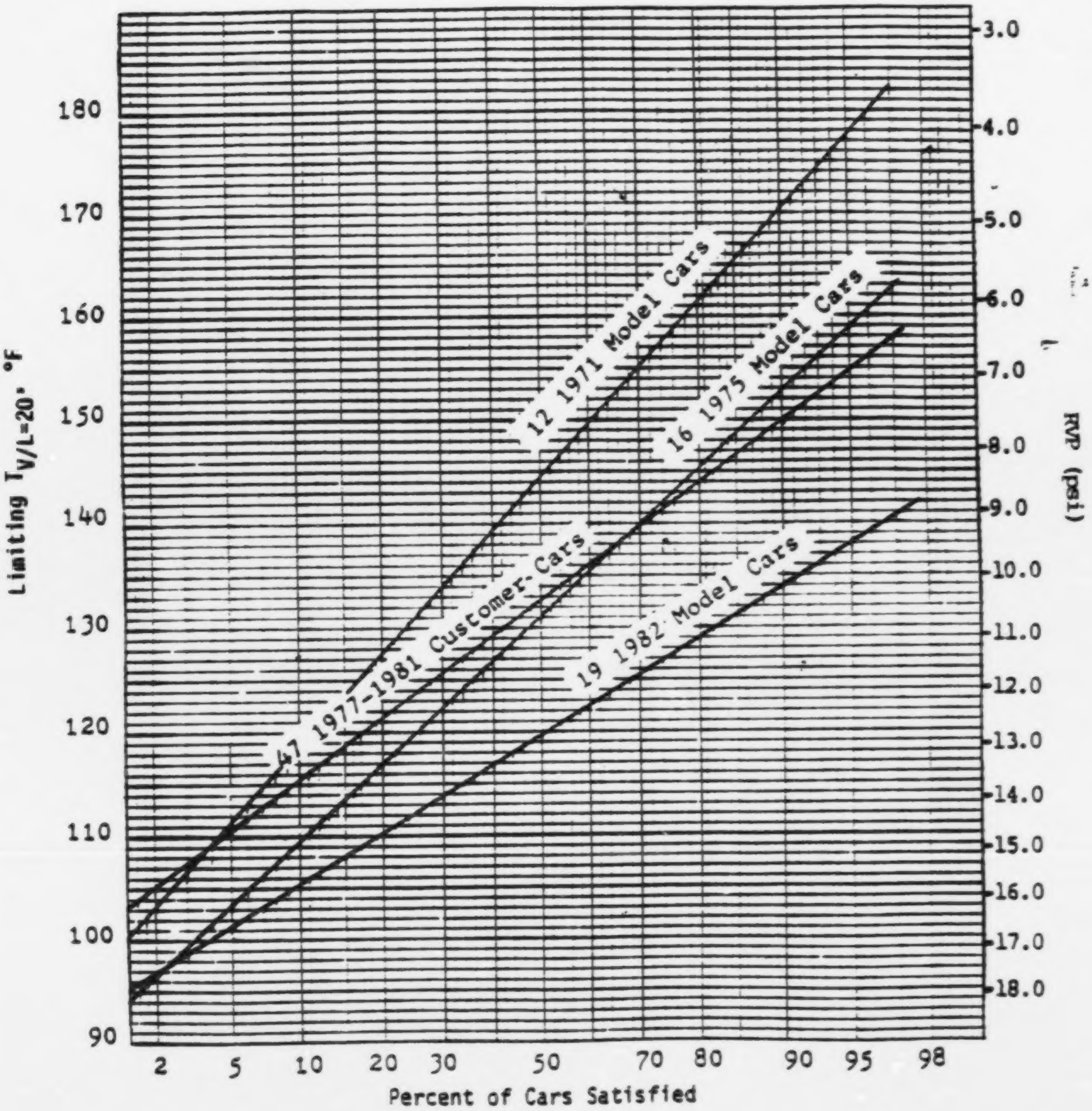

Table 5-22

City Specific Information

City	Population	Vehicle Population*	Average Daily High Temperature Apr	My	JE	JY	Aug	Sept	Oct
New York	17,190,221	9,836,528	60.7	71.4	80.5	85.2	83.4	76.8	66.8
Chicago	7,794,851	4,460,342	59.4	69.7	79.1	83.1	82.3	75.4	65.5
Philadelphia	5,547,902	3,174,601	63.5	74.1	83.0	86.8	84.8	78.4	67.9
Detroit	4,488,072	2,568,149	57.6	68.5	79.1	83.1	81.6	74.2	63.4
Boston	4,303,311	2,462,426	56.3	67.1	76.6	81.4	79.3	72.2	63.2
Washington, D.C.	3,250,822	1,860,174	67.1	76.6	84.6	88.2	86.6	80.2	69.8
Miami	3,220,844	1,843,020	82.7	85.3	88.0	89.1	89.9	88.3	84.6
Houston	2,735,766	1,565,450	79.4	85.9	91.3	93.8	94.3	90.1	83.5
Pittsburgh	2,218,870	1,269,674	60.9	70.8	79.5	82.5	80.9	74.9	63.9
Connecticut Metro	2,206,318	1,262,492	58.9	70.3	79.5	84.1	81.9	74.5	64.3

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* Vehicle population estimated to be 57.222 percent of population based on national average.

Table 5-23

VMT Mix of Vehicle Fleet*

Age of Vehicle	% VMT (as of January)
0	.036
1	.137
2	.122
3	.109
4	.097
5	.085
6	.075
7	.064
8	.056
9	.048
10	.041
11	.041
12	.034
13	.027
14	.021
15	.016
16	.011

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* Based on MOBILE3 information.

Table 5-24

Drivability Cost In Millions*

Fuel RVP	1986	1988	1990**	1992**	1994**	1996**	1998**	2000**	2010
11.5	0	0	0	0	0	0	0	0	0
11.0**	6.2	4.7	3.7	3.0	2.5	2.2	1.8	1.7	1.3
10.5	11.5	8.2	6.6	5.5	4.6	4.0	3.5	3.2	2.1
10.0**	15.3	11.0	9.1	7.7	6.6	5.8	5.0	4.4	2.6
9.5**	18.7	13.2	11.0	9.4	8.2	7.1	6.2	5.5	3.0
9.0	21.5	15.0	12.4	10.6	9.3	8.1	7.1	6.3	3.2
8.5**	24.0	16.4	13.5	11.5	10.0	8.7	7.6	6.7	3.3
8.0**	26.0	17.7	14.5	12.2	10.5	9.1	7.9	6.9	3.3

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* Cost assuming people willing to pay 1¢/gal. extra for better performance fuel.

** Based on a curve fit.

of average monthly high temperatures rather than daily high temperatures may severely under-estimate the associated costs. Also, this analysis was done assuming that people are only paying more for fuel at those times when conditions require it. In reality, these individuals will not know in advance when they will need the better fuel. As a result, they will be paying the extra cost per gallon for a much longer period than we were able to take into account. In addition, these costs savings for volatility control are calculated assuming current fuel volatility is at current ASTM standards. As has been discussed earlier, the national average is already above the ASTM limits, and if it follows the current trends, it could be at much higher levels by the year 2010. Thus, the cost savings in future years to the consumer for volatility control due to driveability would probably also be much higher.

The warranty and vehicle design change costs based on the manufacturer information are not verifiable and required many assumptions. The costs based on the 1¢ to 3¢ price differential are also very rough, as not only is the value a rough estimate, but the estimate of the frequency of poor vehicle performance is also a rough estimate. However, it is difficult to believe that the 1-3¢ per gallon estimate could be too high given its application to only those periods when the vehicle might experience problems, Thus, this represents a more conservative and therefore more defendable estimate.

D. Conclusion

Driveability problems associated with high fuel volatility are real, even though they are not always apparent. Often the problem is diagnosed as a vehicle problem instead of a fuel problem, and thus unfortunately the public misplaces the blame for poor performance on the auto manufacturers.

There have been many studies done which support the idea that high temperature driveability problems increase as fuel volatility increases. Since fuel volatility over the last few years has increased to the point where many of these studies have shown driveability problems associated with vapor lock and fuel foaming, it should be of no surprise that vehicles on the road today experience similar problems.

In addition to the inconveniences caused by driveability problems, there are also direct economic costs associated with them. Costs incurred by manufacturers for warranty problems and vehicle design changes have reached levels possibly as high as $132 million per year. The quantifiable savings to society which might result if volatility were reduced now could reach perhaps $44 million per year based on vehicle hardware reduction. Intangible costs could contribute possibly as much or more. Unfortunately, these cost estimates are based on manufacturer estimates which were extremely vague and therefore could not be verified. An independent method of determining the value to society of improved fuel quality is to use the costs to the consumers due to their willingness to pay an extra 1¢ to 3¢ per gallon extra for better performing fuel. In comparison to other cost estimates seems relatively reasonable. In addition, it is easily broken down by fuel RVP, and can be predicted into the future. The majority of costs based on manufacturer information are costs in the past for design changes. The majority of these may no longer apply to future costs as their effect has already been made. Therefore, although there are many other costs associated with driveability problems due to high volatility, those based on higher fuel costs are the only ones which will receive any further consideration in this study.

VII. Enforcement Costs

The Agency is considering three overall schemes to monitor compliance with gasoline RVP controls: 1) self-reporting by refiners and importers, 2) in-field sampling and testing, and 3) a combination of both.

Under the first option, refiners and importers would be required to test the volatility of fuel and report it to EPA. EPA would prescribe sampling and testing methodologies. Regulated parties would be required to submit periodic reports to EPA and to maintain any records necessary to substantiate their reports. EPA would perform a limited number of audits of regulated parties' records and testing capability to monitor compliance, in addition to reviewing the periodic reports.

Under the second options, the regulatory standard would apply to fuel in the field. Inspectors would take samples at one or more types of fuel distribution facilities according to a prescribed sampling methodology. If an acceptable RVP field screening test were available, it would be performed by the inspector to determine which samples are likely to be in violation of the applicable standard, and only these samples would be shipped to a testing laboratory. If such a screening test were not available, and samples would be tested at the laboratory according to a prescribed methodology. Regulated parties might be required to maintain records to facilitate the tracing of violating samples through the distribution network.

The third option would include both self-reporting and in-field sampling and testing.

A full report investigating the cost of the options above is currently being developed and will be placed in the docket when complete. Preliminary estimates of the costs of different enforcement scenarios based on the above three options are presented in Table 5-25. Option one involves self-reporting by refiners and importers, options two through six involve

Table 5-25

Preliminary RVP Enforcement Cost Estimates

	Scenario	Cost (1000 Dollars)
I.	Self-Reporting	295-477
II.	In-Field Sampling and Testing (10,000 Retail Inspections)	844-2,093
III.	In-Field Sampling and Testing (8,000 Retail and 2,000 Terminal Inspections)	1,465-2,182
IV.	In-Field Sampling and Testing (7,000 Retail, 2,000 Terminal, and 1,000 Refinery Inspections)	1,526-2,289
V.	In-Field Sampling and Testing--Inspection Scheme same as in IV but with Field Screening Test Kit	1,347-1,811
VI.	In-Field Sampling and Testing (8,500 Retail Inspections with States doing 1,500 Retail Inspections themselves)	1,081-1,811
VII.	Self-Reporting and In-Field Sampling and Testing with 50% of the Inspection Scheme in IV	1,356-1,956

in-field sampling and testing scenarios, and option seven involves a combination of self-reporting and in-field sampling and testing. These estimates are based on a year-round basis. With a 5-month standard some estimates might change. For example, additional testing equipment and manpower would be needed to do 10,000 tests in 5 months; also, a contractor might charge more to handle such an intensive inspection scheme. EPA inspector time, travel cost, sampling materials, shipping costs and enforcement resources would remain the same.

The enforcement costs of Table 5-25 are small relative to the other cost of the RVP control program. Even the most expensive option is only approximately two million dollars (including manpower costs) compared to a refinery cost of 490 million dollars for the 9.0 psi control options (total refinery cost to be derived in Chapter 6). For this reason the preliminary cost of enforcement were not included in the cost effectiveness calculations of Chapter 6. The costs will, however, be incorporated when they become finalized. Even if the enforcement cost were included they would not effect the incremental cost effectiveness since the enforcement cost are independent of the RVP level chosen an hence equal at each RVP control step.

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CHAPTER 6

Analysis of Alternatives: Gasoline

This chapter draws on the findings presented earlier in the report and provides a direct comparison of the various HC control strategies being examined (except for alcohol blend strategies, which are addressed in Chapter 7). The bulk of the chapter (Section I) is devoted to the evaluation of RVP control, which is described further below. Following this, in Section II, the control of $\%_{160}$ is evaluated. Two additional analyses are presented in appendices. Appendix 6A evaluates changes in certification fuel at constant in-use RVP (i.e., should certification fuel be matched to Class A, B or C fuel). Appendix 6B evaluates the cost effectiveness of inspection and maintenance programs for evaporative emissions.

The main comparison of RVP control options is based on the estimated costs of motor vehicle-related controls and in-use fuel controls (presented, respectively, in Chapters 4 and 5) and on projected emissions benefits (discussed in Chapter 3) associated with each of the long- and short-term control scenarios. Using this information, cost effectiveness ($ per ton) figures were developed as a basis for evaluation. The emission reductions associated with each control scenario, along with their relative cost effectiveness, will be the focus of this chapter.

Both long-term control strategies, where in-use RVP and certification fuel RVP are made equal, and short-term control strategies, where in-use fuel is temporarily controlled to a lower RVP level than certification fuel, will be examined in terms of cost, emission reductions, and resulting cost effectiveness. The long-term analysis will focus on the year 2010 as a "steady-state" point at which essentially the entire motor vehicle fleet will have turned over (i.e., revised certification fuel and test procedure will have affected the design of almost all of the vehicles in the field). The short-term discussion will examine the years 1988, 1990, 1992, 1995, 1997, and 2000, and will focus on benefits achievable with additional in-use RVP control over and above those benefits resulting from the long-term strategies, again on a calendar year basis (i.e., certification RVP equal to in-use RVP).

Part A of Section I outlines the methodologies and assumptions used to calculate cost effectiveness estimates for both the long- and short-term control strategies. (The discussions on the development of costs and emissions reductions are merely reviews, as the details on both are presented in Chapters 3 through 5.) Following the methodology descriptions, Part B presents the results of the analyses, first for the long-term and then for the short-term strategies.

In Section I, an analysis of alternatives based on best estimates and current conditions will be presented first. This "base" case includes control of vehicle refueling losses (onboard refueling controls are in place) and no inspection and maintenance (I/M) programs for evaporative emissions. As discussed earlier in Chapter 2, ozone-related HC control appears to be most valuable during the summer months, and a 5-month (May-September) control period appeared to be most appropriate. In the analyses performed below both the control period for in-use volatility control and the period of consideration of emission benefits will be five months. This is addressed in greater detail later in Part B. The second analysis presented in Part B adjusts the cost effectiveness of RVP control so that it is comparable to that of other ozone strategies currently being investigated, particularly those which are year-round and focus on these emission reductions in ozone non-attainment areas.

The third analysis presented examines the effect of discounting both costs and emission reductions over a 33 year period prior to calculating a cost per ton. This methodology further increases comparability between RVP control values and those of other ozone programs.

As discussed in Chapter 4, the ratio of percentage change in fuel economy to percentage change in fuel energy content (due to butane removal), designated "R", is between 0.82 and 0.95. All cost effectiveness analyses have been conducted using both ends of this range.

In addition to the base case analysis, Part B will also present the results of various sensitivity analyses. The first sensitivity analysis assumes onboard refueling controls are not in place (i.e., the effect of not implementing onboard vehicle refueling controls or of implementing them "after" RVP controls, either chronologically or for accounting purposes). However, the vehicle-oriented control of excess evaporative HC emissions due to high in-use RVP, which would under some scenarios be controlled with the addition of an onboard canister, is assumed to be controlled via RVP control (certification or in-use) and not via onboard refueling control. This was done because the current evaporative emission excess is not related to refueling and can be controlled without the use of an onboard refueling canister. If the onboard system is not assumed to be present, some control of refueling emissions would be realized with in-use RVP control and reduce the cost per ton of an in-use RVP control program.

The second and third sensitivity analyses will examine the effect of crude oil price on the cost effectiveness. Crude oil prices of $15 per barrel and $25 per barrel will be investigated. The sensitivity of refining cost to crude oil price was described in Chapter 5.

I. RVP Control

A. Methodology

1. Long-Term Analysis

The methodology used to estimate the long-term (steady-state) costs, emission reductions, and resulting cost effectiveness of controlling evaporative HC emissions through equating in-use and certification gasoline RVPs along with revisions to the certification test procedure is detailed in this section. The methodology for calculating the actual cost effectiveness (total costs over total emission reductions) will be presented first for all sensitivity cases, followed by that for adjusting the cost effectiveness of the base case to be comparable to those of other strategies. The HC emission reductions considered in the former calculation all occur in the summer and are, thus, not directly comparable to those of year-round control strategies. The latter calculation adjusts for this difference.

The year 2010 was used to represent the long-term, as the vehicle fleet would consist entirely of post-1990 (i.e., controlled) vehicles by this time.

a. Actual Cost Effectiveness

The 2010 emission reductions associated with the base case (including exhaust HC benefits, with onboard refueling loss control and with no evaporative I/M program), and the without onboard case are estimated in Chapter 3 and were simply taken from total inventory projections of Tables 3-21 and 3-22. As discussed in Chapter 3 the emission reductions used in the cost effectiveness analysis are based on design-value day temperatures. Net and incremental emission reductions were estimated for each long-term control scenario (11.5-psi RVP down to 8.0-psi RVP in 0.5-psi increments).* The sources of NMHC emission reductions include motor vehicle evaporative and exhaust emissions, and gasoline storage and distribution sources (i.e., bulk storage, Stage I, and refueling).

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* The uncontrolled baseline assumes an in-use, Class C equivalent RVP of roughly 11.7 psi -- it varies from city to city -- and a certification fuel RVP of 9.0 psi.

The net and incremental emission reductions estimated for the long-term control scenarios are presented in Table 6-1 for the base case and the without onboard sensitivity analysis. The emission reductions are representative of 5-months of control and are therefore five-twelfth's of the values presented in Tables 3-21 and 3-22. Emission reductions for the crude cost sensitivity cases are the same as the base case. Emission reductions are detailed here in order to provide a perspective on the relative contribution of various sources -- motor vehicle evaporative losses, motor vehicle exhaust emissions, refueling, bulk storage, and Stage I. As shown, motor vehicle evaporative emissions make up the largest controlled category, accounting for 84 to 88 percent of total NMHC reductions in 2010 (assuming the base case).

The only difference between the emission reductions of the without onboard case and the base case is the refueling emission reduction. In the without onboard case, total emission reductions are somewhat higher because in-use RVP control reduces refueling losses if they are not already being controlled by onboard systems. Since in-use RVP control affects even controlled refueling losses (by the same proportions as uncontrolled emissions) and onboard controls would be subject to some degree of tampering, some control of refueling emissions occurs even if onboard controls are implemented. This is demonstrated by the refueling values in the base case of Table 6-1. Based on previous EPA studies, onboard controls are at least 97 percent effective; accounting for the projected tampering incidence (the same as then-current evaporative control tampering rate), refueling emissions are expected to be controlled by 93 percent in 2010 (i.e., essentially all models in the fleet will be equipped with onboard controls).[1]

The net cost of commercial gasoline and motor vehicle-related controls are broken down in Table 6-2 and are a function of several individual components. These include: 1) the refinery costs of reducing gasoline RVP, 2) the value of the increased energy content of commercial gasoline, 3) the value of recovered or prevented evaporative HC losses, 4) the cost of motor vehicle redesign, 5) the fuel economy penalty associated with increased vehicle weight due to the enlarged canister, and 6) the driveability credits. The combination of these individual components is described below. The detailed derivation of the individual vehicle and fuel-related control costs are provided in Chapters 4 and 5, respectively.

The refinery and NGL industry costs of reducing RVP, relative to crude oil price, are taken from Table 5-3 of Chapter 5. For this 2010 scenario the "with investment" costs are most applicable. Nationwide 5-month costs are calculated

Table 6-1

Emission Reductions Under Long-Term 5-Month Control Scenarios in 2010 (10^3 Tons)*

	In-Use = Cert. RVP (psi)							
Case/Category	11.5	11.0	10.5	10.0	9.5	9.0	8.5	8.0
"Base Case" (Net):								
- Evap.HC	505	534	563	587	609	633	652	671
- Exhaust HC	67	67	67	67	67	67	67	67
- Refueling	0	1	1	2	3	3	4	4
- Bulk Storage	2	7	11	15	21	26	31	36
- Stage I	2	8	13	19	20	21	22	23
- Total	576	616	655	690	720	750	776	801
"Base Case" (Incremental)								
- Evap. HC	-	29	29	24	22	24	19	19
- Exhaust HC	-	0	0	0	0	0	0	0
- Refueling	-	1	0	1	1	0	1	0
- Bulk Storage	-	5	4	4	6	5	5	5
- Stage I	-	6	5	6	1	1	1	1
- Total	-	41	38	35	30	30	26	25
"Without Onboard" Case (Net):								
- Evap. HC	505	534	563	587	609	633	652	671
- Exhaust HC	67	67	67	67	67	67	67	67
- Refueling	0	10	19	28	36	45	55	64
- Bulk Storage	2	7	11	15	21	26	31	36
- Stage I	2	8	13	19	20	21	22	23
- Total	576	626	673	716	753	792	827	862
"Without Onboard" Case (Incremental):								
- Evap. HC	-	29	29	24	22	24	19	19
- Exhaust HC	-	0	0	0	0	0	0	0
- Refueling	-	10	9	9	8	9	10	9
- Bulk Storage	-	5	4	4	6	5	5	5
- Stage I	-	6	5	6	1	1	1	1
- Total	-	50	47	43	37	39	35	34

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* Differences in total emissions between Table 6-1 and Table 6-3 are a result of round-off in calculating the components of Table 6-1. Vehicle related emission reductions which occur outside the 5-month control period are ignored.

Table 6-2

Net Costs Under Long-Term, 5-month Control Scenarios in 2010 (10^6 $/yr)

Case/Category	In-Use = Cert. RVP (psi)							
	11.5	11.0	10.5	10.0	9.5	9.0	8.5	8.0
"Base Case":								
- Refinery Cost	0	59	135	223	329	447	583	720
- Vehicle Cost	61	48	36	25	14	4	-7	-15
- Fuel Econ. Credit*	0	-22	-52	-84	-118	-153	-191	-230
- Evap.Recov.Credit	-96	-106	-115	-124	-132	-140	-147	-153
- Driveability Credit	0	-1	-1	-1	-1	-1	-1	-1
- Weight Penalty	11	8	6	4	2	0	-2	-3
- Total Cost	-24	-14	9	43	94	157	235	316
"Without Onboard" Case:								
- Refinery Cost	0	59	135	223	329	447	583	720
- Vehicle Cost	61	48	36	25	14	4	-7	-15
- Fuel Econ. Credit*	0	-22	-52	-84	-118	-153	-191	-230
- Evap.Recov.Credit	-96	-108	-120	-132	-143	-153	-163	-173
- Driveability Credit	0	-1	-1	-1	-1	-1	-1	-1
- Weight Penalty	11	8	6	4	2	0	-2	-3
- Total Cost	-24	-16	4	35	83	144	219	298
"$25 $/bbl Crude Oil" Case:								
- Refinery Cost	0	71	157	264	396	543	706	870
- Vehicle Cost	61	48	36	25	14	4	-7	-15
- Fuel Econ.Credit*	0	-24	-57	-91	-128	-167	-209	-252
- Evap.Recov.Credit	-106	-116	-127	-137	-145	-154	-161	-169
- Driveability Credit	0	-1	-1	-1	-1	-1	-1	-1
- Weight Penalty	12	9	7	5	2	0	-2	-4
- Total Cost	-33	-13	15	65	138	225	326	429
"15 $/bbl Crude Oil" Case:								
- Refinery Cost	0	39	102	178	263	358	473	595
- Vehicle Cost	61	48	36	25	14	4	-7	-15
- Fuel Econ.Credit*	0	-20	-46	-74	-104	-136	-170	-205
- Evap.Recov.Credit	-86	-94	-103	-110	-117	-125	-131	-137
- Driveability Credit	0	-1	-1	-1	-1	-1	-1	-1
- Weight Penalty	10	7	6	4	2	0	-1	-3
- Total Cost	-15	-21	-6	22	57	100	163	234

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* For R = 0.82; when R = 0.95, fuel economy credit is increased by 16 percent.

simply by multiplying these refinery costs by nationwide gasoline consumption (excluding off-highway gasoline consumption) from EPA's MOBILE3 Fuel Consumption Model (FCM) for the year 2010.[2] The annual consumption projected by the MOBILE3 FCM is 74.93 billion gallons (1.784 million barrels) and must be multiplied by five-twelfth's to represent the 5-month control period. The base case refinery costs assume $20 per barrel crude oil. This value was also used in the without onboard and winter-time credit cases. These refinery costs are summarized in Table 6-2. The refinery costs for two additional sensitivity cases assuming $15 per barrel and $25 per barrel crude oil are also shown.

Reducing in-use gasoline RVP also increases the energy density of the gasoline, which, in turn, results in increased fuel economy in motor vehicles. The effects are summarized in Table 5-19 of Chapter 5. The credit is estimated by multiplying the increases in vehicular fuel economy of Table 5-19 by the nationwide fuel consumption described above and an estimated value of gasoline of $0.82 per gallon (for the $20 per barrel crude oil case). Gasoline values of $0.73 and $0.90 per gallon were used in the $15 per barrel and $25 per barrel cases, respectively. A factor of five-twelfths is also included since the credit only occurs during the control period. The resulting credit was multiplied by a R factor of 0.82 to relate the fraction of the increased energy that is fully utilized by the engine. The credits are shown in Table 6-2. For cases where the R-value is 0.95 the credits are simply increased by 16 percent.

The methodology for valuing recovered/prevented evaporative HCs from the gasoline storage and distribution system, vehicle refueling, and motor vehicle operation was derived in Section V of Chapter 5. There, the value of HC (butane) control was determined to be $290.32 per ton (for the $20 barrel per crude oil case). The evaporative and refueling emission reductions can simply be multiplied by this value to derive the recovery credits. The emission reductions used to obtain this credit are based on July-average temperature as discussed in Chapter 3. These emission reductions are shown on a 12-month basis in Tables 3-23 and 3-24 and are generally 28 percent less than the emission reductions of Table 6-1 which are based on design-value temperatures. The emission reductions used to develop an economic credit exclude the portion which is attributed to exhaust emissions (67,000 tons in 2010). The 5-month evaporative recovery credits are shown in Table 6-2.

The costs of vehicle redesign solely for evaporative emission control, on a dollar-per-vehicle basis, are taken from Tables 4-5 thru 4-7 in Chapter 4. These are multiplied by Energy and Environmental Analysis (EEA) vehicle sales projections for the year 2010 to determine annual costs.[3] The resulting annual vehicle design costs are summarized in Table 6-2 and do not vary with sensitivity case.

As alluded to in Chapter 4, redesigning motor vehicles for higher volatility would increase the weight of the motor vehicle slightly, as a larger canister would be required. This weight increase would cause the motor vehicle to consume more fuel over the course of its lifetime than if the vehicle did not have added weight due to redesign. This weight penalty and associated discounted lifetime costs per vehicle are derived in Section II of Chapter 4 and are summarized in Table 4-9. These per-vehicle costs are multiplied by the sales projections described earlier to derive annual costs which are summarized in Table 6-2. The total annual weight penalties are summarized in Table 6-2 for each case.

The driveability credit, derived in Chapter 5, is also summarized in Table 6-2. This credit is taken from Table 5-24 and multiplied by five-twelfth's since the credit only occurs when in-use volatility control is occurring.

The net costs for each control scenario are then calculated by simply adding costs and subtracting credits. Note that the cost calculations take into account the fact that vehicle-related costs occur year-round, while costs and credits associated with commercial fuel volatility control occur over the 5-month period only. (Vehicle-related credits occur either year-round or just in the summer, depending on the case.) The net, long-term, steady-state cost effectiveness is determined by simply dividing the net cost by the 5-month emission reduction. The incremental long-term cost effectiveness is determined first by calculating the incremental cost, then an incremental emission reduction, and finally dividing the incremental cost by the incremental emission reduction.

b. Cost Effectiveness Comparable to Other Strategies

The volatility control cost effectiveness calculated by the above methodology is unique since the control program is seasonally focused. Thus, it is desirable to convert the previous analysis to one that is on the same basis as other ozone reductions programs (e.g., refueling, Stage II, Inspection/Maintenance programs, etc.). The methodology of adjusting the previous analysis for this difference is detailed below.

Nearly all other ozone reduction programs produce emission reductions that occur over a 12 month period, though the ozone-related benefits accrue primarily in the summer. (However, it should be noted that many of the supporting analyses use emission factors that are only representative of summer conditions.) Some programs control emissions only in ozone non-attainment areas. Per ton of emission control, these are the most valuable since they focus control in the areas needing it most. Thus, a cost per ton which assumes year round effectiveness and control only in non-attainment areas is the most useful when comparing strategies.

The base case emission reduction values in Table 6-1 can be converted to a year-round basis by first multiplying by 2.4 (i.e., twelve-fifth's), then by multiplying by 0.395. The first factor simply expands 5-month emission reductions to their 12-month equivalents. The second value represents the fuel consumption in the 61 current, ozone non-attainment areas as a percentage of nationwide fuel consumption. This percentage was calculated using the NEDs data base, which includes county-by-county fuel consumption data for the entire U.S.[4]

The adverse health and welfare effects associated with ozone concentrations in the non-attainment areas are of principal concern, and are the primary focus of this analysis. There are, however, benefits of lowering ozone concentrations in other areas. These benefits occur because some adverse effects appear to have either no threshold level or no clearly defined level below which damage does not occur. Research has identified three areas which are adversely effected at relatively low ozone concentrations: agriculture, non-agriculture vegetation, and materials. The types of damage that occur due to ozone include reduced plant growth, yield, and quality, as well as damage to elastomers, paints, textile fibers, and dyes. These effects are discussed in greater detail in the Onboard/Stage II Regulatory Impact Analysis (RIA).[1]

Assigning an exact monetary value to ozone reductions in attainment areas is difficult. An estimate can be identified, however, based on generally accepted figures. For year-round VOC reductions in attainment areas, $250 per ton has been cited by General Motors in a previous evaluation of hydrocarbon control benefits.[5] This value has been utilized in the Onboard RIA and will be here, as well.

To obtain the attainment area emission reductions, the annual emission reductions which are based on July-average temperature (Table 3-23) were simply multiplied by 0.605. This value represents the fuel consumption in attainment areas (i.e., one minus 0.395). Effective annual emission reductions are used because that was assumed in the development of the $250 per ton estimate. This assumption was made because nearly all VOC control strategies produce year-round emission control and no conversion of the $250 per ton figure would be needed prior to its use. Since the actual benefits occur primarily in the summer, as in non-attainment areas, the same conversion from 5-month to year-round is needed.

The costs for this annualized cost effectiveness analysis are the same as those cited above in Section 1., except for the attainment area credit, since actual costs are used in both cases, which are unaffected by methods to account for ozone benefits. The net long-term, steady state cost-effectiveness is determined by dividing net cost by annual non-attainment area emission reductions. Incremental cost-effectiveness values are determined in the same manner as before using the adjusted incremental costs and emission reductions.

c. 33-Year Discounted Analysis

Both the actual and adjusted cost effectiveness methodologies described above for the long-term are steady-state in nature. That is, they focus on costs and benefits in a given calendar year once all vehicles in the fleet have controls. Start-up costs, such as the cost of implementing vehicle controls while a portion of the fleet is still uncontrolled and not producing emission reductions, are ignored. At the same time, start-up costs only occur once, so long-term programs, such as RVP control, should not be unduly weighed by this effect.

One methodology which attempts to properly weight start-up costs is the 33-year discounted cost effectiveness. It has been used in the analysis of Stage II and onboard vehicle refueling controls, along with the steady-state analysis.[1] Greater weight in this analysis will be placed on the steady-state cost effectiveness. However, the 33-year discounted figures will provide insight into the effect of start-up costs on the analysis, as well as improve comparability with those programs for which a 33-year discounted cost effectiveness has been estimated.

To determine the discounted cost effectiveness the costs and emission reductions for each year over a 33 year period need to be calculated. The net present value of costs and emissions reductions will be determined using a discounting rate of 10 percent. These factors were chosen to be consistent with the analysis performed in the Onboard Refueling RIA.[1] The emission reductions and costs for each of the 33 years are determined analogously to the 2010 analysis above. The annual emission reductions were already presented in Table 3-21. Emission reductions for those years not modeled are linearly interpolated from the modeled years. Emission reductions that occur in the years beyond 2010 are set equal to those achieved in 2010 since the vehicle fleet would consist entirely of post-1990 (i.e., controlled) vehicles by this time and little change will be occurring. Any mileage growth that occurs beyond 2010 would affect both emission reductions and costs to the same degree and should not significantly affect the cost-effectiveness calculation.

The net costs for each year are derived in the same manner as in the long-term methodology outlined above. The specific fuel consumption values for each year were taken from the MOBILE3 Fuel Consumption Model and multiplied by the refinery costs in Table 5-3 (which are based on $20 crude oil price) to determine the refinery cost. The costs of vehicle redesign, on a dollar-per-vehicle basis, are taken from Table 4-9 in Chapter 5. Short-term vehicle costs are used for years 1990-1994. These are multiplied by EEA vehicle sales projections for each individual year.[3] The evaporative recovery credits are obtained by multiplying the July-average emission reductions from Table 3-23 by the butane value of $290.32 per ton developed in Section V of Chapter 4. Net costs are calculated for each year in which emission modeling was performed. Net cost for the years not modeled are linearly interpolated from the modeled years. Net costs beyond 2010 are set equal to the 2010 net cost, consistent with the handling of emission reductions.

The net present value of both emission reductions and net costs are then determined for the 33 year period, then multiplied by the annual annuity factor (33 years at 10 percent). To increase comparability to other strategies, the net present values of both costs and emission reductions are also adjusted, as described in Section 6.2 above, for seasonality and non-attainment area focus prior to the calculation of the cost per ton ratio. Thus, as with the steady-state analysis, both actual and adjusted cost effectiveness figures are presented.

All cost effectiveness estimates (steady-state actual and adjusted and 33-year discounted actual and adjusted) will be presented in Section II. Their relative significance will be analyzed and interpreted as the estimates are presented.

2. Short-Term Analysis

As highlighted elsewhere in this study, ozone control is the primary focus of the various HC reduction strategies being evaluated. Any reductions achievable in the shorter term could be important in view of the Clean Air Act requirement that all urban areas be in attainment of the ozone NAAQS by 1987. Although the long-term strategy is to ensure that certification fuel RVP is representative of in-use levels, a short-term strategy could be to control in-use fuel RVP to a level lower than the long-term certification specification in order to achieve the additional benefits associated only with in-use RVP control. These benefits include: 1) an immediate effect on the entire motor vehicle fleet, including older vehicles not affected by the revised certification fuel, and 2) further control of in-use RVP-related emissions such as gasoline storage, distribution, refueling, and vehicular emissions due to tampering, malmaintenance and defects.

Therefore, a short-term analysis has been performed to focus on the incremental costs and emission reductions of additional in-use RVP control over and above the long-term RVP control strategies. This analysis focuses on the years 1988, 1990, 1992, 1995, 1997 and 2000. As before, the actual cost-effectiveness analysis is described first, followed by the adjusted analysis.

Year-round HC emission inventories with additional short-term in-use RVP control were estimated in Chapter 3 and summarized in Table 3-14; emission reductions were calculated from this table and used directly here for the base case and the without onboard case. As with the long-term analysis, emission reductions for the crude cost sensitivity cases and the winter-time credit case are the same as the base case. As these emission reductions are due solely to in-use RVP control, the emission reductions here are simply five-twelfths of the year-round reductions.

The costs of additional in-use RVP control consist of three parts: 1) refinery costs, 2) credit due to increased fuel density, and 3) credit due to recovered or prevented evaporative emissions. As before, the refinery cost of each 0.5 psi of RVP control was taken from Table 5-3. Here, however, the "no-investment" costs were used for 1988 and 1990, as there would not likely be time for refiners to invest in capital equipment for the most economic RVP control refinery processes. As discussed in Chapter 5 only 0.5 and 1.0 psi decreases in RVP were investigated for this time period since this appears to be the feasible limit of RVP control in a no-investment situation. For the year 1992 it is assumed that sufficient leadtime will be available to enable capital investment to be made in order to meet lower RVP standards. The refinery control costs however would not be equal to the long-term "with-investment" costs. In the long-term analysis annual capital charges were calculated based on amortization of capital over an economic life of 13 years. In the short-term RVP control scenario where RVP restraints may be imposed for a limited period of time (5-10 years), the useful life of the investments would be less than 13 years and the required annual capital charges would be greater than the long-term refinery costs. This issue was investigated in a contractor report by Sobotka and Company for the EPA.[6] The report determined that when capital is amortized over ten years instead of 15 years the cost of RVP reduction increased by an average of 20 percent. This increase is applied to the long-term refinery costs for additional short-term RVP control in the years 1992 to 2000. These costs per barrel were again multiplied by 5-month, on-highway, fuel consumption projections from EPA's MOBILE3 Fuel Consumption Model.[2]

The density-related fuel economy credit for each 0.5 psi of additional RVP control is again taken from Table 5-19 and multiplied by 5-month fuel consumption. The evaporative emission recovery/prevention credit is again obtained by multiplying the 5-month, July-average, emission reductions calculated from Table 3-23 (minus exhaust emissions since their energy is not recoverable by the engine) for additional in-use RVP control by the butane value of $290.32 per ton.

The cost effectiveness is simply the net cost divided by the emission reduction. These estimates of short-term costs per ton will be summarized along with long-term estimates in Section II below.

The adjustments to the actual short-term cost effectiveness to make it comparable with other strategies follows exactly the same methodology as that used in the long-term. Emission reductions were annualized and reduced to represent effective annual reductions achieved in non-attainment areas. The annualized emission reductions occurring in attainment areas were credited at $250/ton and subtracted from the actual net costs to arrive at the adjusted net costs.

B. Cost Effectiveness Comparison of RVP Control Scenarios

1. "Base" Case: Steady-State Analysis

The base case represents the combination of the most likely future regulatory situation and EPA's best technical estimates. As outlined earlier, this includes: 1) onboard control of refueling losses, 2) no evaporative I/M program and 3) an assumption that in-use RVP will continue to rise until ASTM limits are reached (i.e., Class C summertime RVP will equal 11.5 psi, on average, by 1988), except that it will remain constant where it already exceeds ASTM limits.

Actual summation emission reductions, costs, and cost effectiveness estimates are shown for the base case in Tables 6-3 and 6-4 for R-values of 0.82 and 0.95, respectively. The top portions present the long-term (2010) analysis, where certification fuel and in-use fuel RVPs are made equal. The 11.5-psi scenario represents purely vehicle-oriented control as it only requires a change in certification fuel RVP (i.e.,

Table 6-3

"Base" Case: Actual Steady-State Cost Effectiveness, R = 0.82

In-Use Gasoline RVP Control Equal to Revised Cert. Fuel RVP in the Long Term (2010)

In-Use = Revised Cert. Fuel	Emission Reductions (10^3 Tons/Yr)		Net Cost (10^6 \$/Yr)		Cost Effectiveness (\$/Ton)	
RVP (psi)	Net	Incr.	Net	Incr.	Net	Incr.
11.5	576	576	-25	-25	-43	-43
11.0	616	40	-13	11	-22	279
10.5	655	39	8	22	13	562
10.0	689	34	43	35	63	1026
9.5	718	29	95	51	132	1762
9.0	748	30	156	62	209	2084
8.5	774	26	235	79	304	2999
8.0	799	25	316	81	395	3177

Additional In-Use Gasoline RVP Control in the Short Term (1988-2000)

Incremental Control Step	Emission Reductions (10^3Tons)					
RVP (psi)	1988	1990	1992	1995	1997	2000
11.5-11.0	200	185	147	105	83	60
11.0-10.5	169	155	126	90	73	54
10.5-10.0	-	-	101	73	60	46
10.0- 9.5	-	-	80	58	48	38
9.5- 9.0	-	-	68	52	43	35
9.0- 8.5	-	-	40	34	30	28
8.5- 8.0	-	-	36	30	28	25

Incremental Control Step	Incremental Cost Effectiveness (\$/Ton)*					
RVP (psi)	1988	1990	1992	1995	1997	2000
11.5-11.0	99	121	129	251	356	542
11.0-10.5	186	229	301	474	619	871
10.5-10.0	-	-	527	764	957	1266
10.0- 9.5	-	-	1012	1384	1669	2144
9.5- 9.0	-	-	1401	1807	2149	2583
9.0- 8.5	-	-	3033	3500	3845	4110
8.5- 8.0	-	-	3393	3906	4107	4480

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* 1988 and 1990 costs are based on no investment; 1992 and later assume investment has taken place; refinery costs are midway between those of open and fixed NGL purchase scenarios.

Table 6-4

"Base" Case: Actual Steady-State Cost-Effectiveness, R = 0.95

In-Use Gasoline RVP Control Equal to Revised Cert. Fuel RVP in the Long Term (2010)

In-Use = Revised Cert. Fuel	Emission Reductions (10^3 Tons/Yr)		Net Cost (10^6 $/Yr)		Cost Effectiveness ($/Ton)	
RVP (psi)	Net	Incr.	Net	Incr.	Net	Incr.
11.5	576	576	-22	-22	-39	-39
11.0	616	40	-16	7	-25	166
10.5	655	39	1	17	2	430
10.0	689	34	31	30	45	873
9.5	718	29	77	46	107	1575
9.0	748	30	133	56	178	1894
8.5	774	26	206	73	266	2777
8.0	779	25	280	75	351	2935

Additional In-Use Gasoline RVP Control in the Short Term (1988-2000)

Incremental Control Step	Emission Reductions (10^3 Tons)					
RVP (psi)	1988	1990	1992	1995	1997	2000
11.5-11.0	200	185	147	105	83	60
11.0-10.5	169	155	126	90	73	54
10.5-10.0	-	-	101	73	60	46
10.0- 9.5	-	-	80	58	48	38
9.5- 9.0	-	-	68	52	43	35
9.0- 8.5	-	-	40	34	30	28
8.5- 8.0	-	-	36	30	28	25

Incremental Control Step	Incremental Cost Effectiveness ($/Ton)*					
RVP (psi)	1988	1990	1992	1995	1997	2000
11.5-11.0	64	88	91	202	298	466
11.0-10.5	144	189	253	414	546	778
10.5-10.0	-	-	459	675	853	1139
10.0- 9.5	-	-	929	1278	1545	1991
9.5- 9.0	-	-	1305	1686	2009	2418
9.0- 8.5	-	-	2884	3328	3657	3908
8.5- 8.0	-	-	3215	3701	3893	4245

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* 1988 and 1990 costs are based on no investment; 1992 and later assume investment has taken place; refinery costs are midway between those of open and fixed NGL purchase scenarios.

in-use RVP is expected to average 11.5 psi); the 8.0-, 8.5- and 9.0-psi cases, on the other hand, requires primarily in-use fuel control, with improvements to the evaporative emission test procedure but no change in the certification fuel. All of the other RVP scenarios combine the fuel-related and vehicle-oriented approaches. Tables 6-3 and 6-4 show that, in 2010, the vehicle-oriented approach (11.5-psi scenario) is significantly more cost-effective than the scenarios involving fuel control, and actually results in an overall cost savings (i.e., negative cost per ton). This occurs because fuel economy credits from recovered evaporative emissions outweigh the costs of vehicle redesign. However, additional incremental emission control is achievable via more in-use fuel-oriented programs at increasing cost per ton.

The center and bottom portions of Tables 6-3 and 6-4 summarize the short-term analysis, where the strategy is to control in-use fuel RVP to a level lower than the long-term certification specification; after a specified time, in-use fuel control would be relaxed to the long-term certification RVP level chosen via the long-term analysis. The short-term analysis focuses on years between 1988 and 2000 (inclusive). The first column in this portion of the table shows the increment between the long-term certification/in-use specifications and the short-term in-use RVP being evaluated; 0.5-psi increments are shown (e.g., long-term RVP = 11.5, short-term in-use RVP lower at 11.0). The incremental values (based on 0.5-psi intervals) at a given in-use RVP (e.g., 10.0 psi) are the same regardless of long-term certification fuel RVP (e.g., 10.5, 11.0, or 11.5 psi). It should be noted that the emission reductions associated with equating certification and in-use RVPs (i.e., the long-term strategy) are not included in the center portion of the table, but rather only the additional reductions that can be obtained with short-term additional in-use control. The cost per ton estimates for each of these control increments are shown in the bottom portion of the table.

As indicated in Tables 6-3 and 6-4, short-term cost effectiveness ($/ton) rises between 1988 and 2000. This occurs primarily because the emission reductions achievable with additional in-use RVP control decrease with time as the vehicle fleet gradually turns over (i.e., vehicles with larger canisters, designed for the revised long-term certification RVP, beginning with the 1990 model year, start to make up more and more of the in-use fleet). Therefore, incremental costs per ton rises between 1988 and 2000 and eventually exceed the long-term figures shown in the top portion of Tables 6-3 and 6-4, because the short-term refinery costs are higher than those in the long-term due to a shorter, assumed amortization period.

Conceptually, the short-term cost effectiveness figures are used to determine if cost effective emission reductions are achievable at lower RVPs in the short term than in the long term. For example, Table 6-3 shows the long-term cost effectiveness of the 9.5 RVP scenario to be $1762 per ton, and that of the 9.0 RVP scenario to be $2084 per ton. In 1992, emission reductions are available with 9.0 RVP control at $1401 per ton. Thus, one might decide that 9.0 RVP was too costly in the long term but reasonable in the short term. However, Table 6-3 also shows that the short-term cost per ton rises very sharply, so that by 1997 it is essentially the same as the long-term cost effectiveness. Thus, short-term in-use RVP control is generally only available at a lower cost per ton than long-term control for 4-5 years. As the short-term refinery costs assumes amortization of capital investment over 10 years, reducing this to 4-5 years would increase the short-term costs per ton further and probably shorten even further the period during which additional short-term in-use RVP control is more cost effective than long-term control. This is true for essentially all of the control scenarios evaluated in this chapter. Thus, little will be said further about short-term RVP control.

The effect of R-value is shown for the base case by a comparison of Tables 6-3 and 6-4. As indicated in the tables, the higher R-value results in slightly lower costs (due to higher fuel economy credits) and, thus, arithmetically lower cost effectiveness. For example, in the base case analysis of the 9.0-psi long-term scenario, incremental cost/ton decreases by 9 percent, or by $190 per ton, with the higher R-value.

As described in detail in the methodology section above a number of changes were made to the base case, actual cost effectiveness analysis, so that the results would be comparable to year-round ozone reduction strategies in non-attainment areas. The results of this fifth sensitivity analysis are presented in Tables 6-5 and 6-6 for R-values of 0.82 and 0.95, respectively.

The effect of the adjustment to the emission reductions lowered the incremental emission reductions by 1,000 to 2,000 tons per year. This decrease in emission reductions is offset, however, by the $250 per ton credit which is given to the attainment area reductions, which lowered the incremental costs by an average of 10 million dollars. The result is a lowering of the incremental cost effectiveness by approximately $230 per ton for the 9.0 psi RVP control step. It should also be noted that the actual net cost effectiveness was negative for the 11.5 psi and the 11.0 psi control steps, while the adjusted net cost effectiveness is negative at 11.5 psi down to the 8.5 or 9.0 psi step, depending on R-value.

Table 6-5

Base Case: Adjusted Steady-State Cost Effectiveness R = 0.82

In-Use Gasoline RVP Control Equal to Revised Cert. Fuel RVP in the Long Term (2010)

In-Use = Revised Cert. Fuel	Emission Reductions (10^3 Tons/Yr)		Net Cost (10^6 $/Yr)		Cost Effectiveness ($/Ton)	
RVP (psi)	Net	Incr.	Net	Incr.	Net	Incr.
11.5	546	546	-169	-169	-310	-310
11.0	584	38	-170	-1	-291	-21
10.5	621	37	-160	10	-258	267
10.0	653	32	-136	24	-208	750
9.5	681	28	-94	42	-138	1509
9.0	709	28	-42	52	-59	1854
8.5	734	25	27	70	37	2798
8.0	758	24	100	72	132	3000

Additional In-Use Gasoline RVP Control in the Short Term (1988-2000)

Incremental Control Step	Emission Reductions (10^3 Tons)					
RVP (psi)	1988	1990	1992	1995	1997	2000
11.5-11.0	190	175	139	99	78	57
11.0-10.5	160	147	119	85	69	51
10.5-10.0	-	-	96	70	56	43
10.0- 9.5	-	-	75	55	46	36
9.5- 9.0	-	-	64	49	41	34
9.0- 8.5	-	-	38	32	28	26
8.5- 8.0	-	-	34	28	26	24

Incremental Control Step	Incremental Cost Effectiveness ($/Ton)*					
RVP (psi)	1988	1990	1992	1995	1997	2000
11.5-11.0	-187	-161	-154	-22	86	278
11.0-10.5	-108	-62	17	193	348	607
10.5-10.0	-	-	247	494	693	1008
10.0- 9.5	-	-	758	1142	1447	1934
9.5- 9.0	-	-	1157	1582	1929	2387
9.0- 8.5	-	-	2876	3361	3710	3998
8.5- 8.0	-	-	3223	3758	3984	4362

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* 1988 and 1990 costs are based on no investment; 1992 and later assume investment has taken place; refinery costs are midway between open and fixed NGL purchase scenarios.

Table 6-6

Base Case: Adjusted Steady-State Cost Effectiveness R = 0.95

In-Use Gasoline RVP Control Equal to Revised Cert. Fuel RVP in the Long Term (2010)

In-Use = Revised Cert. Fuel	Emission Reductions (10^3 Tons/Yr)		Net Cost (10^6 $/Yr)		Cost Effectiveness ($/Ton)	
RVP (psi)	Net	Incr.	Net	Incr.	Net	Incr.
11.5	546	546	-167	-167	-306	-306
11.0	584	38	-172	-5	-295	-140
10.5	621	37	-167	5	-270	129
10.0	653	32	-148	19	-227	590
9.5	681	28	-112	36	-165	1311
9.0	709	28	-66	46	-93	1653
8.5	734	25	-2	64	-3	2565
8.0	758	24	64	66	85	2744

Additional In-Use Gasoline RVP Control in the Short Term (1988-2000)

Incremental Control Step	Emission Reductions (10^3 Tons)					
RVP (psi)	1988	1990	1992	1995	1997	2000
11.5-11.0	190	175	139	99	78	57
11.0-10.5	160	147	119	85	69	51
10.5-10.0	-	-	96	70	56	43
10.0- 9.5	-	-	75	55	46	36
9.5- 9.0	-	-	64	49	41	34
9.0- 8.5	-	-	38	32	28	26
8.5- 8.0	-	-	34	28	26	24

Incremental Control Step	Incremental Cost Effectiveness ($/Ton)*					
RVP (psi)	1988	1990	1992	1995	1997	2000
11.5-11.0	-223	-196	-194	-74	24	198
11.0-10.5	-153	-104	-33	130	270	508
10.5-10.0	-	-	176	401	584	875
10.0- 9.5	-	-	672	1031	1316	1772
9.5- 9.0	-	-	1055	1454	1781	2213
9.0- 8.5	-	-	2718	3180	3512	3786
8.5- 8.0	-	-	3035	3543	3758	4115

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* 1988 and 1990 costs are based on no investment; 1992 and later assume investment has taken place; refinery costs are midway between open and fixed NGL purchase scenarios.

2. Base Case: 33-Year Discounted Analysis

The 33-year discounted cost effectiveness figures are presented in Tables 6-7 and 6-8. The format of the two tables is slightly different than that of the previous tables since, with 33-year discounting, there is no long- or short-term. The first table (6-7) presents the analysis of actual costs and emission reductions for R equal to 0.82 (top half) and .95 (bottom half). The second table (6-8) present the analysis of adjusted costs and emission reductions.

Comparison of the results of the discounted analysis with the steady-state analysis reveals a number of differences. Net emission reductions are much lower for the discounted analysis, especially at 11.5 psi control (vehicle control) and the first few increments of control. As RVP control approaches 8.0 psi, the net emission reductions approach those of the steady-state analysis. This is explained by the fact that in the steady-state, long-term analysis, it is assumed that essentially the entire fleet consists of vehicles with evaporative emission control systems. The discounted analysis, on the other hand, weighs all of the years prior to the steady-state analysis where, in the first few year, very few vehicles have control systems. Therefore, the more vehicle-oriented control scenarios in the discounted analysis show lower net emissions reductions than the steady-state analysis. This results in an increase in the incremental emission reductions due to in-use RVP control. More emissions are controlled in the early years of a volatility control program by in-use fuel control, and this is reflected in an increase in the incremental emission reductions of the discounted analysis.

The same factors that influence the emission reductions also influence the net costs in the discounted analysis. Initial vehicle costs in all the years of the control program are now realized immediately while the evaporative emission recovery credit in the vehicle-oriented scenarios grows slowly over time. Thus, the evaporative emission recovery credit, which outweighs the vehicle cost in the steady-state analysis, is not large enough in the discounted analysis to offset the cost of the new vehicle hardware. As a result the first two steps of control which were available to the economy at a net savings in the base case are now occurring at a small net cost. As shown in Tables 6-7 and 6-8, although net costs increase, incremental costs do not change nearly as significantly as the incremental emission reductions. The combination is an increase in the net cost effectiveness of all control scenarios. Since the increase however is greater at the vehicle-control end of the cost effectiveness analysis (11.5-11.0 psi RVP) than on the fuel control side (9.0 psi) the result is a decrease in the incremental costs per ton of the

Table 6-7

33-Year Discounted, Actual Cost Effectiveness

R = .82

In-Use = Revised Cert. Fuel	Emission Reductions (10^3 Tons/Yr)		Net Cost (10^6 $/Yr)		Cost Effectiveness ($/Ton)	
RVP (psi)	Net	Incr.	Net	Incr.	Net	Incr.
11.5	411	411	11	11	26	26
11.0	492	82	17	6	35	80
10.5	564	72	35	18	62	250
10.0	624	59	67	32	108	541
9.5	672	48	117	50	175	1038
9.0	715	44	178	60	248	1385
8.5	746	31	257	80	345	2575
8.0	775	28	339	82	438	2670

R = .95

In-Use = Revised Cert. Fuel	Emission Reductions (10^3 Tons/Yr)		Net Cost* (10^6 $/Yr)		Cost Effectiveness ($/Ton)	
RVP (psi)	Net	Incr.	Net	Incr.	Net	Incr.
11.5	411	411	12	12	30	30
11.0	492	82	14	2	28	19
10.5	564	72	26	12	46	171
10.0	624	59	52	26	84	443
9.5	672	48	96	44	143	913
9.0	715	44	151	54	211	1246
8.5	746	31	225	74	301	2388
8.0	775	28	300	75	387	2654

Table 6-8

33-Year Discounted, Adjusted Cost Effectiveness

R = .82

In-Use = Revised Cert. Fuel	Emission Reductions (10^3 Tons/Yr)		Net Cost (10^6 $/Yr)		Cost Effectiveness ($/Ton)	
RVP (psi)	Net	Incr.	Net	Incr.	Net	Incr.
11.5	389	389	- 92	-92	-237	-237
11.0	467	77	-108	-16	-232	-209
10.5	535	68	-111	-3	-208	-45
9.5	591	56	-97	14	-164	254
9.0	637	46	-62	35	-97	773
9.0	678	41	-15	47	-22	1129
8.5	708	29	55	70	77	2376
8.0	734	27	127	72	172	2671

R = .95

In-Use = Revised Cert. Fuel	Emission Reductions (10^3 Tons/Yr)		Net Cost (10^6 $/Yr)		Cost Effectiveness ($/Ton)	
RVP (psi)	Net	Incr.	Net	Incr.	Net	Incr.
11.5	389	389	-91	-91	-233	-233
11.0	467	77	-112	-21	-239	-273
10.5	535	68	-120	-9	-225	-127
10.0	591	56	-112	8	-189	150
9.5	637	46	-83	29	-130	642
9.0	678	41	-42	41	-62	982
8.5	708	29	22	64	31	2178
8.0	734	27	88	66	120	2444

8.0-11.0 RVP scenarios. For 9.0 psi RVP control, the actual incremental cost effectiveness decreases by 34 percent from $1894-2084 per ton to $1246-1385 per ton, depending on R value. The same holds true for the adjusted cost-effectiveness figures.

3. "Without Onboard Control" Case

The first sensitivity case examines the effect of assuming that onboard refueling loss control is not implemented prior to RVP control. Only the actual, steady-state cost effectiveness figures will be compared.

In the base case an onboard implementation date of 1990 was assumed. For all years except 1988 (pre-onboard control), the emission reductions are somewhat higher than under the base case because in-use RVP control would capture a certain percentage of the reductions in refueling losses previously attributed to onboard control. This increase in emission reductions also lowers the cost of the RVP control program to a certain extent due to the slight increase in evaporative recovery credits.

The emission reductions, costs, and resulting cost effectiveness estimates for this without onboard control sensitivity case are presented in Tables 6-9 and 6-10 for R values of 0.82 and 0.95, respectively. The overall effect is an improvement of the cost effectiveness for the fuel-oriented RVP control strategies. For example, the incremental cost effectiveness of the 9 RVP scenario in 2010 without onboard is 27 percent lower ($1380-1519 per ton) versus the base case ($1894-2084 per ton).

4. "Crude Oil Cost" Cases

The second and third sensitivity cases examine the effect of crude oil cost on the actual, steady-state cost effectiveness of RVP control. Two sensitivity cases were run, one with a crude value of $15 per barrel and one with a value of $25 per barrel. The emission reductions, costs, and resulting cost effectiveness estimates for these cases are presented in Table 6-11 through 6-14 with R-value and crude oil price changing alternately.

Table 5-4 of Chapter 5 illustrates the effect of crude oil cost on refinery RVP control cost. Refinery costs are highly dependent on crude oil price since additional crude oil purchases make up a large part of the RVP control cost. This sensitivity is also evident in the net cost of the RVP control program but to a lesser degree. Due to the fixed costs of producing and distributing gasoline, the value of the recovered emissions (retail price minus taxes) is not as strongly

Table 6-9

"Without Onboard" Case: Actual Steady-State Cost Effectiveness, R = 0.82

In-Use Gasoline RVP Control Equal to Revised Cert. Fuel RVP in the Long Term (2010)

In-Use = Revised Cert. Fuel	Emission Reductions (10^3 Tons/Yr)		Net Cost (10^6 \$/Yr)		Cost Effectiveness (\$/Ton)	
RVP (psi)	Net	Incr.	Net	Incr.	Net	Incr.
11.5	576	576	-24	-24	-42	-42
11.0	625	49	-16	8	-26	172
10.5	673	48	3	19	5	399
10.0	716	43	35	32	49	744
9.5	754	38	84	49	112	1309
9.0	793	39	143	59	181	1519
8.5	828	35	220	76	265	2151
8.0	863	35	298	78	345	2258

Additional In-Use Gasoline RVP Control in the Short Term (1988-2000)

Incremental Control Step	Emission Reductions (10^3 Tons)					
RVP (psi)	1988	1990	1992	1995	1997	2000
11.5-11.0	200	185	150	110	89	68
11.0-10.5	169	156	128	96	79	62
10.5-10.0	-	-	103	78	66	53
10.0- 9.5	-	-	83	64	54	45
9.5- 9.0	-	-	70	57	50	43
9.0- 8.5	-	-	43	38	36	34
8.5- 8.0	-	-	38	35	33	33

Incremental Control Step	Incremental Cost Effectiveness (\$/Ton)*					
RVP (psi)	1988	1990	1992	1995	1997	2000
11.5-11.0	99	120	121	225	311	448
11.0-10.5	186	228	289	430	547	730
10.5-10.0	-	-	507	698	835	1049
10.0- 9.5	-	-	966	1242	1451	1725
9.5- 9.0	-	-	1341	1622	1811	2078
9.0- 8.5	-	-	2843	3037	3135	3244
8.5- 8.0	-	-	3152	3310	3382	3379

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* 1988 and 1990 costs are based on no investment; 1992 and later assume investment has taken place; refinery costs are midway between those of open and fixed NGL purchase scenarios.

Table 6-10

"Without Onboard" Case: Actual Steady-State Cost Effectiveness, R = 0.95

In-Use Gasoline RVP Control Equal to Revised Cert. Fuel RVP in the Long Term (2010)

In-Use = Revised Cert. Fuel	Emission Reductions (10^3 Tons/Yr)		Net Cost (10^6 \$/Yr)		Cost Effectiveness (\$/Ton)	
RVP (psi)	Net	Incr.	Net	Incr.	Net	Incr.
11.5	576	576	-22	-22	-38	-38
11.0	625	49	-17	5	-27	103
10.5	673	48	-2	15	-3	308
10.0	716	43	25	28	35	635
9.5	754	38	69	44	92	1174
9.0	793	39	123	53	155	1380
8.5	828	35	193	70	233	1988
8.0	863	35	265	72	307	2082

Additional In-Use Gasoline RVP Control in the Short Term (1988-2000)

Incremental Control Step	Emission Reductions (10^3 Tons)					
RVP (psi)	1988	1990	1992	1995	1997	2000
11.5-11.0	200	185	150	110	89	68
11.0-10.5	169	156	128	96	79	62
10.5-10.0	-	-	103	78	66	53
10.0- 9.5	-	-	83	64	54	45
9.5- 9.0	-	-	70	57	50	43
9.0- 8.5	-	-	43	38	36	34
8.5- 8.0	-	-	38	35	33	33

Incremental Control Step	Incremental Cost Effectiveness (\$/Ton)*					
RVP (psi)	1988	1990	1992	1995	1997	2000
11.5-11.0	64	104	101	197	276	402
11.0-10.5	144	203	259	390	499	669
10.5-10.0	-	-	459	635	762	960
10.0- 9.5	-	-	904	1164	1361	1620
9.5- 9.0	-	-	1262	1528	1707	1959
9.0- 8.5	-	-	2694	2887	2981	3083
8.5- 8.0	-	-	2986	3136	3204	3200

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* 1988 and 1990 costs are based on no investment; 1992 and later assume investment has taken place; refinery costs are midway between those of open and fixed NGL purchase scenarios.

Table 6-11

"15 $/bbl Crude Oil" Case: Actual Steady-State Cost Effectiveness Analysis, R = .82

In-Use Gasoline RVP Control Equal to Revised Cert. Fuel RVP in the Long Term (2010)

In-Use = Revised Cert. Fuel	Emission Reductions (10^3 Tons/Yr)		Net Cost (10^6 $/Yr)		Cost Effectiveness ($/Ton)	
RVP (psi)	Net	Incr.	Net	Incr.	Net	Incr.
11.5	576	576	-15	-15	-26	-26
11.0	616	40	-20	-5	-33	-126
10.5	655	39	-7	14	-10	352
10.0	689	34	21	28	31	813
9.5	718	29	56	35	78	1188
9.0	748	30	99	44	133	1473
8.5	774	26	162	63	210	2400
8.0	799	25	234	71	292	2801

Additional In-Use Gasoline RVP Control in the Short Term (1988-2000)

Incremental Control Step	Emission Reduction (10^3Tons)					
RVP (psi)	1988	1990	1992	1995	1997	2000
11.5-11.0	200	185	147	105	83	60
11.0-10.5	169	155	126	90	73	54
10.5-10.0	–	–	101	73	60	46
10.0- 9.5	–	–	80	58	48	38
9.5- 9.0	–	–	68	52	43	35
9.0- 8.5	–	–	40	34	30	28
8.5- 8.0	–	–	36	30	28	25

Incremental Control Step	Incremental Cost Effectiveness ($/Ton)*					
RVP (psi)	1988	1990	1992	1995	1997	2000
11.5-10.0	-12	3	-1	68	125	226
11.0-10.5	134	170	223	363	480	682
10.5-10.0	–	–	441	643	808	1072
10.0- 9.5	–	–	745	1029	1246	1608
9.5- 9.0	–	–	1060	1374	1637	1972
9.0- 8.5	–	–	2519	2908	3195	3415
8.5- 8.0	–	–	3025	3483	3663	3995

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* 1988 and 1990 costs are based on no investment; 1992 and later assume investment has taken place; refinery costs are midway between those of open and fixed NGL purchase scenarios.

Table 6-12

"15 $/bbl Crude Oil" Case: Actual Steady-State Cost Effectiveness Analysis, R = 0.95

In-Use Gasoline RVP Control Equal to Revised Cert. Fuel RVP in the Long Term (2010)

In-Use = Revised Cert. Fuel	Emission Reductions (10^3 Tons/Yr)		Net Cost (10^6 $/Yr)		Cost Effectiveness ($/Ton)	
RVP (psi)	Net	Incr.	Net	Incr.	Net	Incr.
11.5	576	576	-13	-13	-23	-23
11.0	616	40	-21	-8	-34	-202
10.5	655	39	-12	10	-18	250
10.0	689	34	12	24	17	688
9.5	718	29	42	30	59	1031
9.0	748	30	81	39	108	1309
8.5	774	26	139	58	179	2203
8.0	799	25	204	66	256	2585

Additional In-Use Gasoline RVP Control in the Short Term (1988-2000)

Incremental Control Step	Emission Reduction (10^3 Tons)					
RVP (psi)	1988	1990	1992	1995	1997	2000
11.5-11.0	200	185	147	105	83	60
11.0-10.5	169	155	126	90	73	54
10.5-10.0	-	-	101	73	60	46
10.0-9.5	-	-	80	58	48	38
9.5-9.0	-	-	68	52	43	35
9.0-8.5	-	-	40	34	30	28
8.5-8.0	-	-	36	30	28	25

Incremental Control Step	Incremental Cost Effectiveness ($/Ton)*					
RVP (psi)	1988	1990	1992	1995	1997	2000
11.5-11.0	-25	-12	-20	41	91	179
11.0-10.5	112	148	196	325	433	619
10.5-10.0	-	-	397	583	735	978
10.0-9.5	-	-	688	953	1156	1493
9.5-9.0	-	-	987	1282	1528	1842
9.0-8.5	-	-	2386	2755	3027	3236
8.5-8.0	-	-	2867	3301	3472	3786

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* 1988 and 1990 costs are based on no investment; 1992 and later assume investment has taken place; refinery costs are midway between open and fixed NGL purchase scenarios.

Table 6-13

"25 $/bbl Crude Oil" Case: Actual Steady-State Cost Effectiveness Analysis, R = 0.82

In-Use Gasoline RVP Control Equal to Revised Cert. Fuel RVP in the Long Term (2010)

In-Use = Revised Cert. Fuel	Emission Reductions (10^3 Tons/Yr)		Net Cost (10^6 $/Yr)		Cost Effectiveness ($/Ton)	
RVP (psi)	Net	Incr.	Net	Incr.	Net	Incr.
11.5	576	576	-33	-33	-57	-57
11.0	616	40	-10	23	-17	564
10.5	655	39	27	38	42	976
10.0	689	29	76	49	111	1427
9.5	718	30	138	61	192	2101
9.0	748	30	217	80	290	2689
8.5	774	26	311	93	401	3562
8.0	799	25	406	95	508	3752

Additional In-Use Gasoline RVP Control in the Short Term (1988-2000)

Incremental Control Step	Emission Reduction (10^3 Tons)					
RVP (psi)	1988	1990	1992	1995	1997	2000
11.5-10.5	200	185	147	105	83	60
11.0-10.5	169	155	126	90	73	54
10.5-10.0	-	-	101	73	60	46
10.0- 9.5	-	-	80	58	48	38
9.5- 9.0	-	-	68	52	43	35
9.0- 8.0	-	-	40	34	30	28
8.5- 8.0	-	-	36	30	28	25

Incremental Control Step	Incremental Cost Effectiveness ($/Ton)*					
RVP (psi)	1988	1990	1992	1995	1997	2000
11.5-11.0	177	204	219	379	520	766
11.0-10.5	306	358	457	690	885	1225
10.5-10.0	-	-	693	989	1231	1619
10.0- 9.5	-	-	1170	1596	1923	2469
9.5- 9.0	-	-	1739	2234	2654	3184
9.0- 8.5	-	-	3515	4055	4455	4761
8.5- 8.0	-	-	3931	4524	4758	5189

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* 1988 and 1990 costs are based on no investment; 1992 and later assume investment has taken place; refinery costs are midway between open and fixed NGL purchase scenarios.

Table 6-14

"25 $/bbl Crude Oil" Case: Actual Steady-State Cost Effectiveness Analysis, R = 0.95

In-Use Gasoline RVP Control Equal to Revised Cert. Fuel RVP in the Long Term (2010)

In-Use = Revised Cert. Fuel	Emission Reductions (10^3 Tons/Yr)		Net Cost (10^6 \$/Yr)		Cost Effectiveness (\$/Ton)	
RVP (psi)	Net	Incr.	Net	Incr.	Net	Incr.
11.5	576	576	-30	-30	-53	-53
11.0	616	40	-13	18	-20	443
10.5	655	39	20	32	30	834
10.0	689	34	63	43	91	1262
9.5	718	29	118	55	164	1896
9.0	748	30	191	73	256	2480
8.5	774	26	279	87	360	3319
8.0	799	25	367	89	459	3486

Additional In-Use Gasoline RVP Control in the Short Term (1988-2000)

Incremental Control Step	Emission Reduction (10^3 Tons)					
RVP (psi)	1988	1990	1992	1995	1997	2000
11.5-11.0	200	185	147	105	83	60
11.0-11.5	169	155	126	90	73	54
10.5-10.0	–	–	101	73	60	46
10.0-9.5	–	–	80	58	48	38
9.5-9.0	–	–	68	52	43	35
9.0-8.5	–	–	40	34	30	28
8.5-8.0	–	–	36	30	28	25
–						

Incremental Control Step	Incremental Cost Effectiveness ($/Ton)*					
RVP (psi)	1988	1990	1992	1995	1997	2000
11.5-11.0	141	169	198	327	458	685
11.0-10.0	261	316	426	626	807	1125
10.5-10.0	–	–	640	894	1119	1482
10.0-9.5	–	–	1101	1482	1789	2302
9.5-9.0	–	–	1654	2103	2502	3005
9.0-8.5	–	–	3369	3867	4248	4540
8.5-8.0	–	–	3755	4300	4522	4932

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* 1988 and 1990 costs are based on no investment; 1992 and later assume investment has taken place; refinery costs are midway between open and fixed NGL purchase scenarios.

dependent on crude oil price as the refinery control cost. For example, when crude oil drops 19 percent from $20 per barrel to $15 per barrel, the value of recovered emission credits decreases by only 11 percent from $0.82 per gallon to $0.73 per gallon. Thus the net cost of control will change by a greater percentage (either up or down) than the drop in crude oil price. For example, at 9.0 psi RVP the incremental cost of control for the $15 per barrel case is approximately 29 percent lower than the $20 per barrel base case. This results in a similar percentage reduction in incremental cost effectiveness. With crude oil at $25 per barrel incremental cost increase by 38 percent at the 9.0 psi RVP control step with a similar percent increase in cost effectiveness. Overall, a $15 per barrel crude price lowers the cost per ton of RVP control so that one additional 0.5 psi step of RVP control is achievable of the same cost effectiveness. Likewise, a $25 per barrel crude oil price results in one less 0.5 psi of RVP control being available at the same cost per ton.

C. Summary

Based on the technical estimates and assumptions used in the base case analysis, purely vehicle-oriented control (i.e., certification fuel RVP revised to 11.5 psi and improved test procedure) appears to be the most cost-effective approach in the long term. As shown earlier in Table 6-3, a total of 576,000 tons of summertime HC emissions can be eliminated via this strategy in the year 2010 at a net savings of roughly $43 per ton to the public. However, because a change in certification fuel and test procedure can only affect vehicle design, strategies involving in-use RVP control can reduce emissions further. This is possible because in-use RVP levels affect those portions of evaporative emissions attributable to malmaintenance/defects and evaporative system tampering, as well as stationary sources such as gasoline storage, distribution, and vehicle refueling, whereas certification fuel RVP has no impact on these emissions. In 2010, in-use fuel RVP control could eliminate up to an additional 223,000 tons of summertime HC emissions at an incremental cost per ton ranging between $166 and $3177 per ton. When adjusted to be comparable with year-round strategies focused entirely on non-attainment area emissions, the incremental cost per ton of in-use RVP control becomes $140 to $3000 per ton. The 33-year discounted cost per ton for in-use RVP control were $100-850 per ton lower than the actual and adjusted steady-state (year 2010) figures.

Additional short-term in-use RVP control is only as cost effective as long-term RVP control for a period of 4-5 years (i.e., 1992-1997). As this provides little time for amortization of capital costs, it does not appear to offer a significant advantage over long-term control.

The absence of an onboard control program has very little effect on the 11.5 psi RVP control scenario. However, with respect to all other scenarios, it increases incremental emission benefits and slightly decreases incremental costs, so the actual incremental steady-state (2010) cost per ton is decreased by as much as 34 percent, or up to $1000 per ton. The assumption of crude oil cost also influences the cost effectiveness of the 8.0-11.0 RVP scenarios. A 25 percent decrease in the crude oil cost to $15 per barrel decreases cost effectiveness by roughly the same proportions, while a 25 percent increase raises the cost effectiveness by roughly 35 percent.

II. $\%_{160}$ Control

Control of the mid-range volatility has been discussed as a means to achieve further evaporative emission reductions, in addition to in-use fuel RVP control. The purpose of this section is to determine the cost effectiveness of controlling the $\%_{160}$ of in-use fuels (gasohol, methanol blends, and straight gasolines). The evaporative emission reductions, on a per vehicle basis, were determined in Chapter 2 and are extrapolated to the fleet in this section. The costs of controlling the $\%_{160}$ of in-use fuels were developed in Chapter 5.

The $\%_{160}$ point of in-use fuels varies widely for both straight gasolines and alcohol blends even when comparing within the same ASTM classes. Alcohol blends generally have greater $\%_{160}$ values than straight gasolines with increases of up to 10 percent for volatility matched methanol blends and 15 percent for splash-blended gasohol. This is because of the effects of the higher volatile azeotropes formed when alcohol is mixed with straight gasoline. Based on recent summer MVMA fuel survey results, the $\%_{160}$ point of all alcohol blends was assumed to be 10 percent greater than the $\%_{160}$ point of ASTM Class C straight gasolines which was assumed to be 35 percent.

The total emission reductions attributable to a reduction in the $\%_{160}$ point of in-use fuels is a weighting of the tampered and non-tampered emission reductions based on the percentages of tampered and non-tampered vehicles in the fleet. This must be adjusted for the percentage of vehicles in the total fleet which are carbureted (based on miles traveled rather than number of vehicles) and also the percent of the fuel supply of which the $\%_{160}$ is being controlled. A final adjustment is also necessary to extrapolate the emissions reductions from LDVs to the entire vehicle fleet including LDTs and HDVs based on MOBILE3 results. The evaporative HC emission inventories based on a certification fuel RVP and in-use fuel RVP of 9.0 psi were used to calculate the LDV to fleet adjustment factor. The use of other higher RVP cases results in a small change in the adjustment factor but does not affect the final calculations to any extent.

The equation and inputs from the %$_{160}$ analysis presented in Chapter 2 used to calculate the fleetwide emission reductions are presented in Table 6-15. Tables 6-16 and 6-17 contain the predicted fleetwide emissions reductions for both 1990 and 2010 on a gram per mile and annual tonnage basis for the additive and multiplicative approaches (as explained in Section II, Chapter 2), respectively.

The cost effectiveness results in 1990 and 2010 of reducing the %$_{160}$ point of the alcohol blends to current in-use gasoline levels and then reducing all in-use fuels further are shown in Tables 6-18 and 6-19. The cost effectiveness results are based on annual costs (based on the cost of %$_{160}$ control developed in Chapter 5) and annual emission reductions, and are calculated by dividing the cost of volatility control by the emission reductions within each scenario. In 1990 the cost effectiveness range for reducing the %$_{160}$ value of all in-use fuels from 35 percent to 25 percent is $6,670 to $18,610 per ton. The cost effectiveness increases by 2010 to a range of $21,970 to $61,290 per ton. The increase in cost effectiveness is due primarily to the decrease in the percentage of carbureted vehicles in the vehicle fleet whose hot-soak emissions are affected by control of the %$_{160}$ point of in-use fuels.

These cost effectiveness results do not compare favorably with other volatility control cost effectiveness results (calculated on the same annual basis) determined in this chapter. For example, in the case of reducing in-use fuel RVP to 10.5 psi, the short-term incremental cost effectiveness is $229 per ton in 1990 (see Table 6-3). In the long-term, the incremental cost effectiveness for making in-use fuel RVP equal certification fuel RVP at 9.0 psi, is $2,084 per ton in 2010 (see Table 6-3). RVP control is more cost effective than %$_{160}$ control in both the short-term and long-term.

Pursuing the control of the %$_{160}$ of in-use fuels does not appear reasonable at this time from a cost-effectiveness standpoint for either alcohol blends or straight gasoline. It should be noted, these results are based on a limited number of emission test results which were tested at a laboratory whose hot-soak emissions do not match closely EPA's measured hot-soak emissions tested under the same conditions. In addition, the results do not rule out the possibility of placing a cap on %$_{160}$ of certification fuel to current in-use levels to prevent future emission increases due to the effect of %$_{160}$ on hot-soak emissions. As explained in Chapter 2, control of certification fuel %$_{160}$ appears to be cost effective and is already included in the cost effectiveness results of this chapter.

Table 6-15

Emission Reduction Obtainable Through Control of $\%_{160}$ of In-Use Fuels

$$\text{Emission}^{1}\ \text{Reduction} = (\Delta g/\text{test})_{\substack{\text{Non-}\\\text{Tampered}}}\left(\substack{\text{Non-Tampered}\\\text{Fraction}}\right) + (\Delta g/\text{test})_{\text{Tampered}}\left(\substack{\text{Tampered}\\\text{Fraction}}\right)$$

$$\times \left(\frac{\#\text{trips/day}}{\#\text{miles/day}}\right) \times (\text{Annual VMT}) \times \left(\substack{\text{Carbureted fraction of fleet}\\\text{based on miles traveled}}\right)$$

$$\times (\text{Fuel market penetration fraction}) \times \left(\substack{\text{LDV to Fleet}\\\text{Adjustment Factor}}\right)$$

$(\Delta g/\text{test})_{\text{Non-tampered}}$ = dependent on reduction in $\%_{160}$ (see below)
$(\Delta g/\text{test})_{\text{Tampered}}$ = dependent on reduction in $\%_{160}$ (see below)
Non-tampered fraction = 0.97
Tampered fraction[2] = 0.03
#trips/day = 3.02
#miles/day = 31.1
Fuel market penetration fraction: Gasoline = 0.89
Gasohol = 0.07
Methanol = 0.04

%160 Reduction	Additive Method (Δg/test)Non-Tampered Straight Line	Additive Method (Δg/test)Non-Tampered Curve	Multiplicative Method (Δg/test)Non-Tampered Straight Line	Multiplicative Method (Δg/test)Non-Tampered Curve	(Δg/test) Tampered
45-35	0.20	0.34	0.60	0.95	4.99
35-30	0.10	0.11	0.30	0.35	2.50
35-25	0.20	0.18	0.60	0.57	4.99

Year	1990	2010
Fraction of fleet affected[3]	0.455	0.112
Annual Vehicle Miles Travels (VMT)[4]	1561.75 X 10^9	1885.96 X 10^9
LDV to Fleet Adjustment Factor[5]	1.71	1.56

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[1] Emission Reductions in grams. To obtain g/mile, divide by annual VMT

[2] Based on mileage of 50,000 miles and evap. survey. (See Figure 2-8 of this report.)

[3] From "Percent of VMT Accumulated by Fuel Injected Vehicles," EPA memo from Mark Wolcott to Rick Rykowski, January 8, 1986.

[4] Based on MOBILE3 fuel consumption model predictions.

[5] $\text{LDV to Fleet Adjustment Factor} = \dfrac{\text{MOBILE3 Fleetwide Evaporative HC Emissions Inventory}}{\text{MOBILE3 LDV Evaporative HC Emission Inventory}}$

Table 6-16

Emission Reductions Obtainable Through Control of $\%_{160}$ of In-Use Fuels (Additive Method)

Fuel	Final $\%_{160}$	Fleetwide Emission Reductions in 1990			
		Straight Line		Curve	
		g/mi	tons/yr	g/mi	tons/yr
Gasohol	45	*	*	*	*
	35	0.0018	3,130	0.0025	4,360
Methanol	45	*	*	*	*
	35	0.0010	1,860	0.0014	2,490
All Fuels	35	*	*	*	*
	30	0.0130	22,350	0.0137	23,610
	25	0.0260	44,660	0.0245	42,140

Fuel	Final $\%_{160}$	Fleetwide Emission Reductions in 2010			
		Straight Line		Curve	
		g/mi	tons/yr	g/mi	tons/yr
Gasohol	45	*	*	*	*
	35	0.0004	850	0.0006	1,180
Methanol	45	*	*	*	*
	35	0.0002	480	0.0003	680
All Fuels	35	*	*	*	*
	30	0.0029	6,060	0.0031	6,400
	25	0.0058	12,110	0.0055	11,430

---

* Base from which emission reductions are determined.

Table 6-17

Emission Reductions Obtainable
Through Control of $\%_{160}$ of In-Use Fuels
(Multiplicative Method)

		Fleetwide Emission Reductions in 1990			
Fuel	Final $\%_{160}$	Straight Line		Curve	
		g/mi	tons/yr	g/mi	tons/yr
Gasohol	45	*	*	*	*
	35	0.0039	6,660	0.0057	9,740
Methanol	45	*	*	*	*
	35	0.0022	3,800	0.0032	5,570
All Fuels	35	*	*	*	*
	30	0.0277	47,560	0.0313	53,860
	25	0.0553	95,090	0.0531	91,300

		Fleetwide Emission Reductions in 2010			
Fuel	Final $\%_{160}$	Straight Line		Curve	
		g/mi	tons/yr	g/mi	tons/yr
Gasohol	45	*	*	*	*
	35	0.0009	1,800	0.0013	2,640
Methanol	45	*	*	*	*
	35	0.0005	1,030	0.0007	1,510
All Fuels	35	*	*	*	*
	30	0.0062	12,900	0.0070	14,610
	25	0.0124	25,790	0.0119	24,760

---

* Base from which emission reductions are determined.

Table 6-18

1990 Cost Effectiveness of Reducing %$_{160}$ of In-Use Fuels

				Emissions Reductions[2]		Cost Effectiveness[3]	
Fuel	Final %$_{160}$	Pool %$_{160}$	Cost[1] (10^6\$/yr)	Straight Line (tons/yr)	Curve (tons/yr)	Straight Line (\$/ton)	Curve (\$/ton)
Gasohol	45	34.4	*	*	*	*	*
	35	33.7	23.7	3,130-6,660	4,360-9,740	3,560-7,560	2,430-5,440
Methanol	45	35.0	*	*	*	*	*
	35	34.6	13.5	1,790-3,800	2,490-5,570	3,560-7,560	2,430-5,440
All Fuels	35	33.3	*	*	*	*	*
	30	28.2	308.7-387.7	22,350-47,560	23,610-53,860	6,490-17,350	5,730-16,420
	25	23.2	634.0-784.1	44,660-95,090	42,140-91,300	6,670-17,560	6,940-18,610

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* Base from which costs, emission reductions, and cost effectiveness results are determined.

[1] Based on MOBILE3 fuel consumption model prediction of gasoline sales of 79.901 x 10^9 gallons in 1990.

[2] The range of emission reductions listed is for the range from the additive method to the multiplicative method.

[3] The range of cost effectiveness only lists the minimum and maximum ends of the range.

Table 6-19

2010 Cost Effectiveness of Reducing $\%_{160}$ of In-Use Fuels

				Emissions Reductions[2]		Cost Effectiveness[3]	
Fuel	**Final $\%_{160}$**	**Pool $\%_{160}$**	**Cost[1] (10^6 $/yr)**	**Straight Line (tons/yr)**	**Curve (tons/yr)**	**Straight Line ($/ton)**	**Curve ($/ton)**
Gasohol	45	34.4	*	*	*	*	*
	35	33.7	21.2	850- 1,800	1,180- 2,640	11,760- 25,070	8,020- 17,880
Methanol	45	35.0	*	*	*	*	*
	35	34.6	12.1	480- 1,030	680- 1,510	11,760- 25,070	8,020- 17,880
All Fuels	35	33.3	*	*	*	*	*
	30	28.2	275.7- 346.4	6,060- 12,900	6,400- 14,610	21,370- 57,160	18,870- 54,130
	25	23.2	566.5- 700.6	12,110- 25,790	11,430- 24,760	21,970- 57,850	22,880- 61,290

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* Base from which costs, emission reductions, and cost effectiveness results are determined.

[1] Based on MOBILE3 fuel consumption model prediction of gasoline sales of 71.395 x 10^9 gallons in 2010.

[2] The range of emission reductions listed is for the range from the additive method to the multiplicative method.

[3] The range of cost effectiveness only lists the minimum and maximum ends of the range.

References (Chapter 6)

1. "Draft Regulatory Impact Analysis: Proposed Refueling Emission Regulation for 1990 and Later Model Year Gasoline - Fueled Motor Vehicles, Volume I, Analysis of Gasoline Marketing Regulatory Strategies." EPA, Office of Air Quality Planning and Standards and Office of Mobile Sources. (Available in public docket A-87-11.)

2. "MOBILE3 Fuel Consumption Model," Mark A. Wolcott, EPA, and Dennis F. Kahlbaum, CSC, February 1985, EPA-AA-TEB-EF-85-2.

3. "The Motor Fuel Consumption Model: Twelfth Periodical Report," Energy and Environmental Analysis, Inc., For U.S. Department of Energy, November 1985.

4. "Fuel Consumption Fraction in Ozone Problem Areas and Impact on Onboard Cost-Effectiveness Analysis," EPA memorandum from Terry P. Newell to Charles L. Gray, Jr., July 7, 1986.

5. "Public Hearing on the EPA Study of Gasoline Volatility and Hydrocarbon Emissions from Motor Vehicles," Ann Arbor, MI., February 4-5. 1986. (Public Docket No. A-85-21, Entry II-F-1.)

6. "Cost and Feasibility of Gasoline Volatility Reductions," Sobotka and Company, Inc., for EPA Office of Policy Analysis, April 21, 1986.

Appendix 6A

Selection of a Certification Fuel RVP

The selection of the severity of conditions for the FTP for evaporative emissions is of critical importance, as this will determine the capacity of the evaporative emission control system for all new gasoline-fueled vehicles. With respect to exhaust emissions it has been the goal to set the conditions of the FTP to be representative of what vehicles experience in the real world. However, since control systems for evaporative emissions are not proportional control devices (i.e. once canister breakthrough conditions are reached none of the subsequent evaporative emissions are trapped until such time as the canister is purged), controlling emissions from vehicles experiencing conditions of "average" severity is not sufficient. Therefore, it is appropriate to design the FTP to represent more "worst case" conditions.

When comparing the temperature and fuel tank level conditions of the current FTP to in-use conditions, it appears that the FTP resembles ASTM Class C areas fairly well. Using the methodology outlined in Chapter 2, the Uncontrolled Diurnal Indices (UDI) for the 61 non-California urban ozone non-attainment areas were calculated using design value day temperatures and ASTM fuel RVP with average vehicle conditions (i.e., 61 percent full fuel tank). The UDI for the FTP was calculated using the temperatures and fuel tank level of the diurnal test procedure and fuel RVP levels of 9.0 (Class A), 10.0 (Class B) and 11.5 psi (Class C). The results of these calculations are shown in Table 6-A-1.

The analysis shows that, for 9.0 and 10.0 RVP fuel, the UDI of the FTP is less than that calculated for the great majority of the cities (59 and 53 out of 61, respectively). Using Class C fuel (RVP=11.5), the FTP UDI is much more representative of the UDIs for the 61 non-attainment cities, (28 out of 61 UDIs are greater than that of the FTP). Hence, setting certification fuel volatility specifications to match ASTM Class C fuel volatility specifications appears to be the most reasonable approach. However, since it is desirable to cost effectively control as many emissions as possible, ideally an analysis of the cost effectiveness of increasing certification test stringency would identify the point at which the increased emission reductions achieved are no longer worth the cost.

The ability to perform such an analysis is limited by our current model of evaporative emissions, notably the treatment of driving cycles. For instance, many vehicles may experience only partial diurnals each day, being interrupted by driving (and therefore purging of the canister) during the day. Other vehicles may not be driven for periods of two days or more, during which time multiple diurnals are experienced and the evaporative canister may become saturated with hydrocarbons. Some vehicles are driven consistently on long trips resulting in complete cannister purge, while others are consistently driven for very short periods, where the ensuing hot-soaks may always exceed the cannister purge. In addition to driving cycles, at this time it is difficult to address the impact the presence of an onboard refueling vapor recover canister would have on the results of this analysis.

These limitations are much more relevant in an analysis of certification test stringency than in assessing the point at which to match in-use and certification fuel. Increasing certification fuel RVP and, therefore, design stringency only affects the emissions from vehicles with operational control systems, albeit the great majority of vehicles. Since canister purge plays an integral role in the operation of any evaporative control system, and purge is strongly dependent on driving cycle. The in-use efficiency of the control system is very dependent on vehicle driving cycle. This deficiency is not too serious for estimating average emissions since the certification procedure simulates these conditions directly. However, the deficiency increases as one departs from the average and moves toward those conditions where evaporative emissions are high, such as those mentioned above. Since the increased capture of these highly uncontrolled emission situations is precisely the focus of a cost effectiveness analysis of certification test stringency, the potential for error due to the limitations of the current evaporative emission procedure are particularly high. Therefore, it must be stressed that the analysis performed below must be considered very preliminary.

The certification test can be made more stringent in a number of ways. It can be done by decreasing the fuel tank level of test vehicles, increasing the span of the diurnal heat build, or by adjusting the certification fuel RVP. However, since both diurnal and hotsoak emissions are best correlated with fuel RVP, RVP was the parameter which was varied in this analysis to simulate different levels of stringency for the FTP.

The first step of the cost effectiveness analysis was to determine the cost of raising the certification fuel RVP from the present level of 9.0 psi RVP up to as high as 12.5 psi RVP (in increments of 0.5 psi RVP). The vehicle control costs for the different certification fuel RVP levels could be taken directly from Table 4-3.

In the second step, average non-tampered emissions were calculated on a per vehicle basis for each certification fuel scenario for the nine largest, non-California U.S. cities*, and were then weighted according to population and combined to obtain an overall average emission value. All emission calculations were performed using ozone non-attainment design value temperatures and a 61 percent full fuel tank (as derived in Chapter 2, Section III-A-1d), while assuming that in-use fuel RVP matched ASTM summer specifications (e.g., Class C = 11.5 RVP). From these emission calculations, emission reductions for each incremental increase in fuel RVP were determined.

A fuel recovery credit was also calculated for each certification fuel RVP level, due to the expected increased efficiency of vehicle control systems with increasing certification fuel RVP. These fuel recovery credits were determined using average July temperatures for each city and assuming a 53 percent full fuel tank (see Chapter 2, Section III-A-1e). Two scenarios were used, one in which it was assumed that the fuel recovery credit was experienced over the entire year, and one in which the fuel recovery was assumed to take place only five months of the year (i.e., only during the summer months when evaporative emissions are well understood and presumably higher).

Cost effectiveness calculations were then performed assuming a ten year vehicle life. Emission reductions and fuel recovery credits were discounted over the ten year period using both a 0 percent (which is analogous to the year 2010, steady state analysis of Chapter 6) and 10 percent (standard for EPA mobile source analysis) discounting rate. The results of this analysis, including the fraction of nontampered emissions which would be eliminated under each certification fuel scenario are shown in Table 6-A-2. It should be pointed out that the cost effectiveness numbers shown here differ somewhat from those presented in the main body of Chapter 6. This is due to the fact that the emissions model used in this appendix was relatively simplistic compared to the emissions model used in the other sections.

Focusing on the results of the analysis assuming a zero percent discount rate and 5-month recovery credit, which are most consistent with those of Chapter 6, it appears that raising certification fuel from 9.0 psi RVP to 10.0 psi RVP would not only reduce emissions, but would also introduce a net savings to consumers, since savings due to the fuel recovery credit would outweigh the cost of improving the evaporative emission control system on new vehicles. Raising certification fuel volatility further, up to 11.5 psi RVP (independent of the fuel recovery credit timeframe), would produce a net consumer cost (i.e. the incremental manufacturing cost would outweigh the incremental fuel recovery credit), but would still reduce emissions at a relatively low incremental cost effectiveness (less than $200 per ton). Within the accuracy of the emissions model this confirms that setting certification fuel to match in-use fuel in Class C areas is reasonable. Since it appears that emissions reductions would be achieved at moderate expense, one could conclude therefore that the test procedure was not being made too stringent. In addition, once certification fuel RVP is increased above 11.5 psi RVP, it appears that emission reductions would become increasingly costly, but would still not be unreasonable, on the order of $500-1000 per ton. However, due to the aforementioned limitations in the analysis, particularly the treatment of driving cycles, no confident conclusion can be drawn at this time.

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* Miami was not used in the analysis as the ozone design value day for this city was atypical in that it was a winter day.

It should also be pointed out that the results of this analysis are influenced by certain assumptions contained in the equations used to model emissions. Reasonably accurate equations exist which correlate diurnal emissions with fuel RVP, fuel temperature increase, and fuel tank vapor space volume. Hot soak emissions, however, can currently only be correlated with in-use fuel RVP. According to the model, once certification fuel RVP is raised past the in-use level (11.5 psi here), hot soak emission reduction through increasing certification RVP is no longer possible. The sharp increase in the cost of emission reductions once certification RVP exceeds 11.5 psi (see Table 6-A-2), therefore,is the result of this aspect of the model.

One other useful result shown in Table 6-A-2 is the fraction of current non-tampered evaporative emissions which would be eliminated by raising the certification test procedure RVP to various levels. Since many cities currently are not in compliance with ozone regulations, it may be fair to say that the current test procedure conditions fall considerably short of the desired level of control. Looking at the fraction of evaporative emissions eliminated in conjunction with the cost effectiveness of each certification test stringency scenario may help in determining how stringent the FTP for evaporative emissions ought to be.

Table 6-A-2

Costs Effectiveness of Increasing Certification Fuel RVP
(per Vehicle Basis)

A. 5 Month Fuel Credit

Initial Cert RVP	New Cert RVP	Additional Manufacturer Cost ($)	Emission Reduction (g/yr)	Percentage of Present Emissions Eliminated	Fuel Credit (g/yr)	Fuel Credit ($/yr)	Discounted Emission Reductions (grams)		Discounted Fuel Credit ($)		Incremental Cost Effectiveness ($/ton)	
							0% Disc.	10% Disc.	0% Disc.	10% Disc.	0% Disc.	10% Disc.
9.0	9.5	0.59	1266.9	20.3	354.95	.0937	12669.0	8173.8	.937	.6045	-24.8	-1.6
9.5	10.0	0.62	924.8	35.1	258.61	.0683	9248.0	5966.7	.683	.4404	- 6.2	27.3
10.0	10.5	0.62	674.2	45.9	187.26	.0494	6742.0	4349.7	.494	.3189	17.0	62.8
10.5	11.0	0.66	487.2	53.6	133.61	.0353	4872.0	3143.4	.353	.2275	57.2	124.8
11.0	11.5	0.70	346.5	59.2	93.13	.0246	3465.0	2235.6	.246	.1586	118.9	219.7
11.5	12.0	0.84	125.4	61.2	14.91	.0039	1254.0	808.8	.039	.0254	579.5	913.7
12.0	12.5	0.86	77.6	62.4	5.77	.0015	776.0	500.7	.015	.0098	987.8	1540.4

B. 12 Month Fuel Credit

Initial Cert RVP	New Cert RVP	Additional Manufacturer Cost ($)	Emission Reduction (g/yr)	Percentage of Present Emissions Eliminated	Fuel Credit (g/yr)	Fuel Credit ($/yr)	Discounted Emission Reductions (grams)		Discounted Fuel Credit ($)		Incremental Cost Effectiveness ($/ton)	
							0% Disc.	10% Disc.	0% Disc.	10% Disc.	0% Disc.	10% Disc.
9.0	9.5	0.59	1266.9	20.3	851.88	.2249	12669.0	8173.8	2.249	1.4510	-118.8	-95.6
9.5	10.0	0.62	924.8	35.1	620.67	.1638	9248.0	5966.7	1.638	1.0568	- 99.9	-66.4
10.0	10.5	0.62	674.2	45.9	449.41	.1186	6742.0	4349.7	1.186	.7652	- 76.2	-30.3
10.5	11.0	0.66	487.2	53.6	320.66	.0846	4872.0	3143.4	.846	.5461	- 34.6	32.9
11.0	11.5	0.70	346.5	59.2	223.52	.0590	3465.0	2235.6	.590	.3807	28.8	129.6
11.5	12.0	0.84	125.4	61.2	35.79	.0094	1254.0	808.8	.094	.0610	539.7	873.8
12.0	12.5	0.86	77.6	62.4	13.84	.0037	776.0	500.7	.037	.0236	962.1	1515.4

Table 6-A-1

61 Non-California Urban Ozone Non-Attainment Areas and Associated Design Value Day UDIs

Area	ASTM Class	UDI *
EPA Region 1		
Boston Metro Area	C	3.017
Greater Connecticut Metro Area	C	1.649
New Bedford, MA	C	1.603
Portland, ME	C	0.838
Portsmouth-Dover-Rochester, NH-ME	D	2.285
Providence, RI	C	2.521
Springfield, MA	D	3.309
Worcester, MA	C	1.730
EPA Region 2		
Atlantic City, NJ	C	2.915
New York Metro Area	C	1.976
Vineland-Millville-Bridgeton, NJ	C	2.310
EPA Region 3		
Allentown-Bethlehem, PA	C	2.462
Baltimore, MD	C	2.813
Erie, PA	C	1.505
Harrisburg-Lebanon-Carlisle, PA	C	1.722
Lancaster, PA	C**/D	1.297
Philadelphia Metro Area	C	1.665
Pittsburgh, PA	C	1.594
Reading, PA	C	1.858
Richmond-Petersburg, VA	D/C**	1.773
Scranton-Wilkes Barre, PA	D	2.661
Washington, DC-MD-VA	C	1.432
York, PA	C	2.045
EPA Region 4		
Atlanta, GA	C/B**	1.619
Birmingham, AL	C	2.470
Charlotte-Gastonia-Rock Hill, NC-SC	B	2.840
Chattanooga, TN-GA	B	2.257
Huntington-Ashland, WV-KY-OH	C	3.274
Louisville, KY-IN	C	2.263
Memphis, TN-AR-MS	B**/C	1.240
Miami-Hialeah, FL ***	C	2.198
Nashville, TN	C	2.772
Tampa-St. Petersburg-Clearwater, FL	C	1.603

Table 6-A-1 (cont)

Area	ASTM Class	UDI
EPA Region 5		
Akron, OH	C	1.432
Canton, OH	C	2.500
Chicago Metro Area	C	2.270
Cincinnati Metro Area	C	1.361
Cleveland, OH	C	2.087
Dayton-Springfield, OH	C	4.034
Detroit, MI	C	1.517
Grand Rapids, MI	C	1.806
Indianapolis, IN	C	1.684
Milwaukee Metro Area	C	2.510
Muskegon, MI	C	1.929
EPA Region 6		
Baton Rouge, LA	B**/C	1.102
Beaumont-Port Arthur, TX	B	1.619
Brazoria, TX	B	1.606
Dallas-Fort Worth, TX	B	1.535
El Paso, TX	A	1.196
Galveston-Texas City, TX ***	B	0.750
Houston, TX	B	1.181
Lake Charles, LA	C/B**	1.063
Longview-Marshall, TX	B	1.798
New Orleans, LA	C	2.356
San Antonio, TX	B	1.673
Tulsa, OK	B	2.524
EPA Region 7		
Kansas City, MO-KS	B	1.490
St. Louis, MO-IL	B	1.533
EPA Region 8		
Denver-Boulder, CO	B**/A	2.447
Salt Lake City-Ogden, UT	B**/A	2.102
EPA Region 9		
Phoenix, AZ	A	2.168
Certification Temperature & Tank Level Conditions	A(9.0)	1.000
	B(10.0)	1.309
	C(11.5)	1.958

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* Assuming a 61% full gas tank.

** ASTM Class assumed in analysis.

*** Based on highest ozone day during May to September period (measured at same monitoring station at which the ozone design value occurred).

Appendix 6-B

Evaluation of an Inspection/Maintenance Program for Evaporative Emission Control Systems

This appendix details the calculations used to derive the benefits and cost effectiveness of an in-use vehicle inspection and maintenance (I/M) program for evaporative emission control systems. The program is assumed to begin in 1988. This was the earliest feasible implementation date for evaporative I/M. Application was restricted to 1978 and later model year LDVs and LDTs. Earlier vehicles were not certified using the comprehensive SHED test and so their evaporative emission control systems are not very effective and are not amenable to cost-effective repair. Heavy-duty vehicles were not included since many current I/M programs for exhaust emissions do not inspect HDVs.

This appendix is arranged into six sections describing how the emissions benefits, costs and cost effectiveness of evaporative I/M were estimated. The sections are:

- Sources of Excess Evaporative Emissions
- Evaporative I/M Program Design
- Effectiveness of Evaporative I/M
- Evaporative I/M Program Scenarios
- Evaporative I/M Costs
- Evaporative I/M Cost Effectiveness

The first section describes how the excess emissions of evaporative systems were estimated. The second section describes how an evaporative inspection would be performed. The next section discusses the expected effectiveness of evaporative I/M programs. The fourth section describes the two I/M programs analyzed in this appendix. The fifth section presents estimates of the costs associated with evaporative I/M programs. The last section calculates the cost effectiveness for 1988 and for 2010, representative of the long-run

Sources of Excess Evaporative Emissions

The emission reductions obtainable through an evaporative I/M program were based on results from EPA's in-use emission factors (EF) test program, which is described in Chapter 2. Tables 6-B-1 and 6-B-2 present the types of malmaintenance and defect (M&D) problems discovered in the EF test program and the rate of occurrence of each problem for fuel-injected (FI) and carbureted vehicles, respectively. Tables 6-B-1 and 6-B-2 also present the average diurnal and hot-soak emission effect associated with each problem, as measured in the EF test program vehicles.

Table 6-B-1

In-Use EF Test Program M&D Types, Rates of Occurrence and Average Emissions for Fuel-Injected Vehicles (11.7 psi Fuel)

Evaporative Control Problem	Vehicles With Diurnal Problems	Vehicles With Hot Soak Problems	Vehicle Average Emissions (grams/test)	
			Diurnal	Hot Soak
Gas Cap Leaks	4	4	20.64	3.35
Purge System Plugged/Damaged	3	3	18.50	10.48
Purge Hose Disabled	–*	1	–	38.15
Saturated Canister	2	2	16.33	2.11
Plugged/Dirty Filter	7	7	14.49	5.66
Canister Damaged	–	1	–	13.06
Air Cleaner Throttle Body Gasket Missing	1	1	22.96	3.22
Average Emissions Vehicles with Any Problem	17	19	17.36	7.53
Average Emissions Vehicles with No Problems	146	144	7.56	2.07
Average Emissions Of All Vehicles	163	163	8.51	2.70
Fleet M&D Effect			0.95	0.63

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* If the average emissions of vehicles with a problem was less than the average of vehicle without problems; then they were added to the without problem sample for that mode.

Table 6-B-2

In-Use EF Test Program M&D Types, Rates of Occurrence and Average Emissions for Carbureted Vehicles (11.7 psi Fuel)

Evaporative Control Problem	Vehicles With Diurnal Problems	Vehicles With Hot Soak Problems	Vehicle Average Emissions (grams/test)	
			Diurnal	Hot Soak
Gas Cap Leaks	11	11	13.87	6.61
Canister Hose Damaged	1	1	17.18	3.91
Purge System Plugged/Damaged	19	19	15.22	7.38
Saturated Canister	8	-*	10.55	-
Plugged/Dirty Filters	4	4	8.66	3.23
Bowl Hoses Damaged	4	-	11.73	-
Air Cleaner Throttle Body Gasket Missing	1	-	17.67	-
Combinations	6	6	14.48	10.39
Average Emissions Vehicles With Any Problem	45	41	13.51	7.11
Average Emissions of Vehicles with No Problems	110	114	8.63	3.32
Average Emissions Of All Vehicles	155	155	10.33	4.26
Fleet M&D Effect			1.70	0.96

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* If the average emissions of vehicles with a problem was less than the average of vehicle without problems; then they were added to the without problem sample for that mode.

Although the percentages used for M&D problems in this analysis are based on the observed rates in the sample, there is no reason to believe that many of the problems observed in the fuel-injected sample or the carbureted sample will occur only in those groups. For example, the rate of leaking gas caps is larger for carbureted than fuel-injected vehicles. There is probably no good reason why the rates would be so different, other than sampling variation. The emission levels themselves are subject to this same sampling variability. As a result some vehicles with identified M&D problems have emission levels which are less than the average emissions of vehicles without identified problems. Both of these factors make the estimates of the potential emission reductions from the evaporative I/M uncertain at best. Only more information on the extent of M&D problems and the actual measured reductions from repairs of those problems can help reduce this uncertainty. This analysis will, however, provide a basis for discussion of the relative value of the concept of evaporative I/M and whether more investigation is warranted.

The percentage of the total M&D effect due to each defect is contained in Tables 6-B-3 and 6-B-4 for fuel-injected and carbureted vehicles, respectively. The percentages were calculated using the following equation and then normalized. (All negative percentage contributions were assumed to be zero before the total percentage was normalized.)

$$\frac{\left(\begin{array}{c}\text{Avg Evap Emissions}\\ \text{With a M\&D Problem}\end{array} - \begin{array}{c}\text{Emissions With}\\ \text{No Problems}\end{array}\right)}{\begin{array}{c}\text{Overall}\\ \text{Fleet M\&D Effect}\end{array}} \times \begin{array}{c}\text{Rate of}\\ \text{Occurrence}\\ \text{of M\&D}\\ \text{Problem}\end{array} = \begin{array}{c}\text{Percent}\\ \text{of Fleet}\\ \text{M\&D}\\ \text{Effect}\end{array}$$

Evaporative I/M Program Design

There are two basic I/M program designs. Centralized programs inspect all vehicles at a few large inspection stations with multiple "lanes" so that more than one vehicle can be inspected at once. These stations are usually run by the local I/M agency or by a contractor. Repairs are not done at the inspection station. The inspection in centralized programs must be done quickly in order to avoid long waiting lines. Decentralized I/M programs license independent garages or repair facilities to conduct inspections. Usually, the vehicles are both inspected and repaired at the time of the inspection.

Evaporative emissions caused by malmaintenance and defects (M&D) can usually be detected by a careful functional and visual inspection of the system. To detect a leaky gas cap, the fuel tank is sealed off and pressurized through its connection to the charcoal canister. A drop in pressure noted with a pressure gauge indicates a possible leaking gas cap. The exhaust

Table 6-B-3

Percentages of Total M&D Effect Due to Specific M&D Problems on Fuel-Injected Vehicles

Problem	Percentages of Total M & D Diurnal	 Hot Soak
Gas Cap Leaks*	31.35	4.95
Purge System Plugged/ Damaged	19.69	24.30
Purge Hose Disabled*	-	34.75
Saturated Canister	10.54	0.10
Plugged/Dirty Filter	29.20	24.22
Canister Damaged*	-	10.54
Air Cleaner Throttle Body Gasket Missing	9.22	1.11
Total	100.00	100.00
Total Percentage Addressable with Evaporative I/M	51.04	74.54

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* Problem is addressable with M&D Evaporative I/M

Table 6-B-4

Percentages of Total M&D Effect Due to Specific M&D Problems on Carbureted Vehicles

	Percentages of Total M & D	
Problem	Diurnal	Hot Soak
Gas Cap Leaks*	21.87	23.14
Canister Hose Damaged*	3.24	0.42
Purge System Plugged/ Damaged	47.52	49.43
Saturated Canister	5.83	-
Plugged/Dirty Filters	0.05	0.0
Bowl Hoses Damaged*	4.72	-
Air Cleaner Throttle Body Gasket Missing	3.44	-
Combinations	13.33	27.01
Total	100.00	100.00
Total Percentage Addressable with Evaporative I/M	77.35	72.99

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* Problem is addressable with M&D evaporative I/M.

emission analyzer can also be used to "sniff" for leaks while the system is pressurized. To detect a broken/missing gasket, propane is sprayed around the intake manifold in an engine at idle. An increase in engine RPM when the propane is applied would indicate a broken/missing gasket. Broken or cracked canisters and damaged hoses are detected visually.

Leaking gas caps, missing or broken carburetor gaskets, broken canisters and damaged hoses are all assumed to be detectable. Tables 6-B-3 and 6-B-4 contain the maximum percentage of the M&D effect addressable through an evaporative I/M program broken down into the diurnal and hot-soak components.

Any gas caps, canisters and connecting hoses which have been removed or disconnected are considered to be tampered. Tampering can usually be detected by a quick visual inspection of the system. Table 6-B-5 contains rates of tampering observed in recent EPA tampering surveys.[7]

Effectiveness of Evaporative I/M

In operating I/M programs, the actual effectiveness of tampering inspections in eliminating the emission impacts of tampering is less than 100 percent. This is due to factors such as sloppy inspections, fraud and retampering between inspections. It is assumed that inspections for evaporative system tampering can be up to 70 percent effective when conducted in centralized I/M programs.[6] Actual experience with decentralized underhood inspections, however, suggest that an evaporative I/M inspection as part of a decentralized program may be only about half as effective. This observed difference in effectiveness is thought to be caused by differences in inspector training, motivation and oversight in centralized versus decentralized programs. Benefits from inspection of vehicles for tampering are estimated by reducing the rate of tampering and then recalculating the emission impact of the remaining tampering. The emission impact of evaporative system tampering has already been discussed in Chapter 2.

Table 6-B-6 contains the maximum portion of M&D effects addressable through an evaporative I/M program which is 100% effective. Table 6-B-6 also shows the portion of M&D effects addressable through evaporative I/M programs which are 70% effective. For this analysis, functional M&D inspections in I/M programs will be assumed to be only as effective in identifying and correcting evaporative system problems as visual tampering inspections.

Evaporative I/M Program Scenarios

Two scenarios for annual inspections of the evaporative system in I/M programs were investigated. The first assumes that thorough inspection for M&D problems combined with an evaporative system tampering check can be accomplished in

Table 6-B-5

Types of Tampering Problems And Typical Rates of Occurrence

Problem	Rate of Occurrence (%)
Gas Cap Removed	1.2%
Canister Vacuum Disconnected	1.7
Cap Removed & Canister Vacuum Disconnected	0.1
Canister Removed	0.3
Non-vacuum Canister Disconnection	0.2
Total Disablements	3.5%

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* Rates calculated from the combined data from the EPA Tampering surveys performed in 1982, 1983 and 1984 (9,142 vehicles).

Table 6-B-6

Portion of M&D Effects Addressable Through M&D Evaporative I/M

	@ 100% Effectiveness		@ 70% Effectiveness	
Vehicle Type	Diurnal	Hot Soak	Diurnal	Hot Soak
Fuel Injected	77%	73%	54%	51%
Carbureted	51%	75%	36%	52%

centralized I/M programs (Case #1). This represents the most optimistic case for evaporative I/M. The second scenario assumes that there is only the visual inspection for evaporative system tampering (no M&D checks) and that this inspection occurs in a decentralized setting (Case #2). This case represents a program design more likely to be implemented. The two scenarios show a range of possible reductions possible from an evaporative I/M program.

Although the first optimistic scenario (Case #1) is included in the analysis it is not likely to be implemented in any of the existing I/M areas. Existing centralized inspection programs were designed with an expected vehicle inspection throughput and inspection times as short as two minutes per vehicle. Any change in the inspection procedure which would result in more time for each inspection would cause long lines at the inspection stations and angry vehicle owners. It would be necessary to build more inspection lanes at each station or build new stations to absorb longer inspection times. The required evaporative system pressure checks and propane leak checks also generate concerns about liability for accidents, accidental damage to vehicles and possible negative public reaction. It is not likely that any State agency responsible for an I/M program would proceed with an evaporative I/M approach with these program elements without considerable pressure from EPA or environmental groups. As long as there are other, more easily implemented options available, centralized I/M program planners will likely avoid adding an evaporative I/M program of this type.

Many I/M programs are considering changing the frequency of their inspections to biennial (every other year). Biennial inspections would reduce the number of inspections required each year and allow inspection times at centralized inspection stations to be lengthened without building new inspection facilities. However, the inspections necessary in Case #1 described above will more than double the inspection time in most centralized programs. This will more than offset the reduction in the inspection load from switching from an annual to a biennial inspection frequency. Also, changing inspection frequency will not address the liability concerns and will reduce the benefits of both the evaporative and exhaust emission portions of the program.

An underhood tampering inspection in a decentralized inspection program (Case #2), however, can be done and is currently being done in some areas. Liability is not as much a concern for this scenario since the inspection is strictly visual. Also, requiring repairs to tampering is not considered as controversial since some vehicle owner responsibility is assumed.

MOBILE3 emission factors were determined based on the predicted percentage reductions in M&D emissions and tampering occurrences. The MOBILE3 M&D emission components (i.e., carbureted hot-soak and diurnal, fuel injected hot-soak and diurnal) were reduced by the percentages listed in Table 2-B-6 for the centralized (Case #1) I/M program. The MOBILE3 M&D components were not changed for the decentralized (Case #2) I/M program. The MOBILE3 LDV and LDT tampering rates (on 1978 and later vehicles) were reduced 70 percent or 35 percent depending upon which I/M program was being evaluated. The MOBILE3 results were then used to determine the emissions inventory according to the methodology described in Chapter 3.

An evaporative I/M program would only be practically instituted in areas with existing I/M programs. These are best represented by ozone non-attainment areas. VOC emission reductions are shown in Table 6-B-7 for 61 non-California ozone non-attainment areas obtained with an evaporative I/M program assuming the current in-use RVP or ASTM limit, whichever RVP is higher for each city. For the year 2010, a case is also presented which assumes volatility control to 9.0 psi in ASTM Class C areas. This assumes proportional reductions (from 22 percent) in ASTM non-Class C areas. For MOBILE3 modeling, 15 of the 61 areas, including the 10 largest areas and five other geographically diverse areas, were chosen to represent the 61 non-attainment areas. The use of only these 15 areas should not significantly affect the results of the analysis.

Evaporative I/M Costs

The costs of an evaporative I/M program arise from the two steps of an I/M program, the inspection and the repair of the malmaintained, defective and/or tampered parts.

The cost per inspection assumes additional inspector time per vehicle (in addition to the time required for an exhaust inspection) at a labor rate of $20/hour. The increase in time for a M&D inspection is primarily due to the procedure necessary to check for leaky gas caps. When combined with an underhood inspection for other M&D problems and for tampering, the inspection is assumed to add six inspector minutes to the existing inspection time or $2 per inspection. The underhood tampering inspection alone is assumed to add three inspector minutes or $1 per inspection.

Table 6-B-8 contains the estimated costs of the parts and the amount of time necessary to carry out the repairs. The part costs and labor time estimates are based on typical costs of parts and labor time found in Mitchells Mechanical Parts/Labor Estimating Guides. Labor costs are based on a basic shop fee of $35/hour. The assumed repair costs associated with each problem for fuel-injected and carbureted vehicles on both a repaired

Table 6-B-7

Emission Reductions Obtainable with Evaporative I/M Programs In 61 Non-California Non-Attainment Areas*

(1000 tons/year)

	Calendar Year			
	Case #1		Case #2	
Assuming Current In-Use ASTM RVP Fuel*	1988	2010	1988	2010
Baseline (no program) Case	6998.7	7698.9	6998.7	7698.9
With Evaporative I/M	6935.7	7603.9	6986.7	7678.2
Program Benefit	63.0	95.0	12.0	20.7

	Calendar Year	
	Case #1	Case #2
Assuming Volatility Control to 9.0 psi in ASTM Class C**	2010	2010
Baseline (no program) Case	7028.4	7028.4
With Evaporative I/M	6976.1	7017.3
Program Benefit	52.3	11.1

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* The model assumes whichever RVP is higher for each city. All scenarios assume a 9.0 psi RVP certification fuel.

** Proportional reductions (from 11.5 psi) are assumed for ASTM non-Class C areas.

Case #1 refers to an annual inspection of the evaporative control system which includes a leak check and a thorough underhood examination for tampering, cracked hoses and damaged canisters in a centralized program.

Case #2 refers to an annual visual inspection of the evaporative control system for missing and disabled components (tampering) in a decentralized program.

Table 6-B-8

Evaporative I/M Estimated Parts and Labor Repair Costs

Evaporative Part Replaced	Parts Cost ($)	Labor Time (hours)	Total Cost
Gas Cap	10	0.0	10.00
Intake Gasket	10	3.0	115.00
Vacuum Hoses	2	0.3	12.50
Carburetor Gasket	40	1.4	89.00
Evaporative Canister	50	0.5	67.50

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* Parts cost and labor time was estimated based on "Mitchell Mechanical Parts/Labor Estimating Guide" for Domestic Cars and Imported Cars and Trucks 1984. Published by Mitchell Manuals Inc., San Diego, California, 1984. A basic shop fee of $35.00/hour labor cost was used for all assumed repairs.

vehicle and average in-use vehicle basis are listed in Tables 6-B-9 and 6-B-10. Inspection costs and the combined inspection and repair costs are shown as well.

The total first year repair cost will be greater than the total second (and subsequent) year repair cost. This occurs because during the first year of the evaporative I/M program (1988), existing problems in all of the vehicles from model years back to 1978 must be repaired. In the second and subsequent years, only the cars which have had malmaintenance and defect problems and/or have been tampered with within the last year will need to be repaired.

If we assume that none of the M&D problems existed when the vehicles were new, then based on the average age of the vehicles an average rate for the occurrence of new problems could be estimated. The average age of vehicles in the fleet is about five years, therefore 20 percent of the observed problems would occur every year if the rate of occurrence is assumed to be linear. This is complicated by the fact that some of the problems are likely to be the result of manufacturing defects which should not be counted in the rate of new occurrences. It is not possible to determine for certain if a M&D problem is a defect or a result of in-use deterioration, therefore for this analysis a reoccurrence rate of 15 percent will be assumed. Thus, the second year (and subsequent) repair costs are 15 percent of the first year repair costs. The incremental inspection cost remains unchanged since all vehicles must still be inspected.

Tampering is assumed to also reoccur. Since deliberate tampering is a behavior, it's reoccurrence cannot be assumed to be random and therefore linear. The assumed penalty for tampering, in this case simply the repair of the tampered item, is not likely to be a strong deterrent factor. The reoccurrence rate for tampering is assumed to be 25 percent for this analysis. This includes both new occurrences on previously untampered vehicles and actual reoccurrence on previously tampered vehicles.

The combined repair and incremental inspection costs are calculated in Table 6-B-11 and Table 6-B-12 separately for each scenario. The resultant evaporative I/M costs for the fuel-injected and carbureted vehicles are the same for the tampering only inspection (Case #2).

An economic credit is realized from the emission repairs required in the evaporative I/M program. The excess emissions which would have been lost without repairs to the evaporative control system will now be captured by the charcoal canister and combusted in the engine. The economic credit is determined as explained previously in Chapter 5, by assuming the composition of the emissions is all butane. Chapter 5 contains the values used to convert the butane to a gasoline equivalent and then to economic credits (i.e., to develop the butane value of $290.32

Table 6-B-9

Evaporative I/M Repair Cost Per Vehicle Inspected For Fuel-Injected Vehicles

M&D Problem	Rate(%)	Repair Cost($)	Repair Cost Per Vehicle($)
Leaking Gas Cap	3.6	10.00	$0.36
Leaking Gasket	3.6	115.00	4.14
Broken Canister	1.8	67.50	1.22
M&D Repair Cost per Inspection			$5.72
Tampering Problem			
Gas Cap Removed	1.2	10.00	$0.12
Canister Vacuum Disconnected	1.7	12.50	0.21
Cap Removed & Canister Vacuum Disconnected	0.1	22.50	0.02
Canister Removed	0.3	67.50	0.20
Canister Mechanically Disconnected	0.2	12.50	0.03
Tampering Repair Cost per Inspection			$0.58

Table 6-B-10

Evaporative I/M Repair Cost Per Vehicle Inspected For Carbureted Vehicles

M&D Problem	Rate(%)	Repair Cost($)	Repair Cost per Vehicle($)
Leaking Gas Cap	5.5	10.00	$0.55
Damaged Vacuum Line	5.5	12.50	0.69
Damaged Vent Line	0.9	12.50	0.11
Leaking Carburetor	0.9	89.00	0.80
M&D Repair Costs per Inspection			$2.15
Tampering Problems			
Gas Cap Removed	1.2	10.00	$0.12
Canister Vacuum Disconnected	1.7	12.50	0.21
Cap Removed & Canister Vacuum Disconnected	0.1	22.50	0.02
Canister Removed	0.3	67.50	0.20
Canister Mechanically Disconnected	0.2	12.50	0.03
Tampering Repair Cost per Inspection			$0.58

Table 6-B-11

Calculation of Total Evaporative I/M Cost Per Vehicle Inspected For Fuel-Injected Vehicles

Case #1 (Full Inspection)

First Year M&D Repair Cost (at 70% Effectiveness)	$4.00
First Year Tampering Repair Cost at 70% Effectiveness	0.41
Incremental Inspection Cost	2.00
First Year Cost per Vehicle	$6.41
Subsequent Year M&D Repair Cost with 15% Reoccurrence and at 70% Effectiveness	$0.60
Subsequent Year Tampering Repair Cost with 25% Reoccurrence and at 70% Effectiveness	0.10
Incremental Inspection Cost	2.00
Subsequent Year Cost per Vehicle	$2.70

Case #2 (Tampering Inspection)

First Year Tampering Repair Cost at 35% Effectiveness	$0.20
Incremental Inspection Cost	1.00
First Year Cost per Vehicle	$1.20
Subsequent Year Tampering Repair Cost with 25% Reoccurrence and at 35% Effectiveness	$0.05
Incremental Inspection Cost	1.00
Subsequent Year Cost per Vehicle	$1.05

Table 6-B-12

Calculation of Total Evaporative I/M Cost Per Vehicle Inspected For Carbureted Vehicles

Case #1 (Full Inspection)

First Year M&D Repair Cost (at 70% Effectiveness)	$1.51
First Year Tampering Repair Cost at 70% Effectiveness	0.41
Incremental Inspection Cost	2.00
First Year Cost per Vehicle	$3.92
Subsequent year M&D Repair Cost with 15% Reoccurrence and at 70% Effectiveness	$0.23
Subsequent Year Tampering Repair Cost with 25% Reoccurrence and at 70% Effectiveness	0.10
Incremental Inspection Cost	2.00
Subsequent Year Cost per Vehicle	$2.33

Case #2 (Tampering Inspection)

First Year Tampering Repair Cost at 35% Effectiveness	$0.20
Incremental Inspection Cost	1.00
First Year Repair & Inspection Cost per Vehicle	$1.20
Subsequent year Tampering Repair Cost with 25% Reoccurrence and at 35% Effectiveness	$0.05
Incremental Inspection Cost	1.00
Subsequent Year Cost per Vehicle	$1.05

per ton, or $0.32 per kilogram). Tables 6-B-13, 6-B-14 and 6-B-15 contain the resultant fuel recovery credits for the evaporative I/M program for 1988 and 2010, respectively.

Evaporative I/M Cost Effectiveness

The total number of vehicles affected by an evaporative I/M program were based on 61 non-California ozone non-attainment areas. It was determined that 39.5 percent of nationwide VMT occurs in these areas and, therefore, it was assumed that 39.5 percent of the nationwide fleet is found in the ozone non-attainment areas. The total size of the nationwide fleet was taken from estimates in the MOBILE3 fuel consumption model.[8] Carbureted and fuel-injection projections back to 1978 (for the 1988 analysis), and back to 1990 (for the 2010 analysis) were taken from MOBILE3. The I/M cost without the fuel recovery credit is a weighted-average of the total inspection and repair cost for fuel-injected and carbureted vehicles. The fuel recovery credit, as described in the previous section, is subtracted from the inspection and repair cost to obtain the I/M cost with the fuel recovery credit. The I/M cost with the fuel recovery credit is the final cost of the evaporative I/M program and is divided by the emission reductions listed in Table 6-B-7 to determine the cost effectiveness (C/E) of the evaporative I/M program. The resulting C/E numbers are shown in Table 6-B-13, 6-B-14 and 5-A-15.

Tables 6-B-13 and 6-B-14 present the derivation of the C/E of an evaporative I/M program in 1988 (first year) and 2010, respectively, assuming current in-use or ASTM RVP fuel. The first scenario analyzed assumes that a full inspection of the evaporative control system is performed each year which will identify both maintenance and defects and identify evaporative system disablements and removals (tampering) in a program with centralized inspection stations. The second scenario assumes that evaporative I/M consists of only the visual inspection for evaporative system tampering performed in a decentralized (garage based) program. As was discussed earlier, these two scenarios show the range of program benefits. The second (tampering only) scenario, however, is the most likely to be implemented if evaporative I/M were to be added to the existing exhaust emission I/M programs. This is due to the impact a full M&D and tampering inspection would have on the total inspection time per vehicle in a centralized inspection program.

Both Tables 6-B-13 and 6-B-14 utilize costs and emission reductions based on the vehicle population of 61 non-California ozone non-attainment areas. This has little effect on the final cost-effectiveness for any particular evaporative I/M program since most areas' vehicles should be similar in vehicle mix and emissions to this fleet. Therefore, the cost effectiveness numbers could be applied to any city where an evaporative I/M

Table 6-B-13

Cost Effectiveness of Evaporative I/M
1988 (First Year, No RVP Control)

Total number of vehicles affected by Evaporative I/M program*

	FI	Carb.
LDV	15.2×10^6	22.8×10^6
LDT	2.3×10^6	7.1×10^6
Total	17.5×10^6	29.9×10^6

Cost of Inspection and Repair per Vehicle (first year)

	FI	Carb.
Case#1	FI = $6.41	Carb. = $3.92
Case#2	FI = $1.20	Carb. = $1.20

Costs and Benefits

	Case #1	Case #2
Cost of Inspection and Repair	$\$2.29 \times 10^8$	$\$0.57 \times 10^8$
Fuel Recovery Credit**	$\$0.18 \times 10^8$	$\$0.04 \times 10^8$
Total Costs & Credits:	$\$2.11 \times 10^8$	$\$0.53 \times 10^8$
Emission Reduction due to Evap I/M***	63,000 tons	12,000 tons
Cost Effectiveness:	$3350/ton	$4420/ton

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* Based on the vehicle VMT of 61 non-California ozone non-attainment areas, MOBILE3 fuel consumption model total number of 1978 and newer model year vehicles, MOBILE3 vehicle registration distributions and MOBILE3 projections of the number of carbureted and fuel injected vehicles.

** Fuel recovery credit was determined at $290.32/ton assuming the recovered emissions were butane. The recovered emissions were determined using MOBILE3 with average July temperatures.

*** Emission reductions were determined using MOBILE3 with ozone design value day temperatures.

Table 6-B-14

Cost Effectiveness of Evaporative I/M 2010 (Subsequent Years, No RVP Control)

Total number of vehicles affected by Evaporative I/M program*

	FI	Carb.
LDV	53.6×10^{6}	6.8×10^{6}
LDT	11.9×10^{6}	1.5×10^{6}
Total	65.5×10^{6}	8.3×10^{6}

Cost of Inspection and Repair per Vehicle (after first year)

Case#1	FI = $\$2.70$	Carb. = $\$2.33$
Case#2	FI = $\$1.05$	Carb. = $\$1.05$

Costs and Benefits

	Case #1	Case #2
Cost of Inspection and Repair	$\$1.96 \times 10^{8}$	$\$0.77 \times 10^{8}$
Fuel Recovery Credit**	$\$0.26 \times 10^{8}$	$\$0.06 \times 10^{8}$
Total Costs & Credits	$\$1.70 \times 10^{8}$	$\$0.71 \times 10^{8}$
Emission Reduction due to Evap I/M***	95,000 tons	20,700 tons
Cost Effectiveness	$1790/ton	$3430/ton

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* Based on the vehicle VMT of 61 non-California ozone non-attainment areas, MOBILE3 fuel consumption model total number of 1978 and newer model year vehicles, MOBILE3 vehicle registration distributions and MOBILE3 projections of the number of carbureted and fuel injected vehicles.

** Fuel recovery credit was determined at $290.32/ton assuming the recovered emissions were butane. The recovered emissions were determined using MOBILE3 with average July temperatures.

*** Emission reductions were determined using MOBILE3 with ozone design value day temperatures.

Table 6-B-15

Cost Effectiveness of Evaporative I/M
2010 (Subsequent Years, With RVP Control)

Total number of vehicles affected by Evaporative I/M program*

	FI	Carb.
LDV	53.6×10^6	6.8×10^6
LDT	11.9×10^6	1.5×10^6
Total	65.5×10^6	8.3×10^6

Cost of Inspection and Repair per Vehicle (after first year)

Case#1 FI = \$2.70 Carb. = \$2.33
Case#2 FI = \$1.05 Carb. = \$1.05

Costs and Benefits

	Case #1	Case #2
Cost of Inspection and Repair	\$1.96 x 10^8	\$0.77 x 10^8
Fuel Recovery Credit**	\$0.13 x 10^8	\$0.03 x 10^8
Total Costs & Credits	\$1.83 X 10^8	\$0.74 x 10^8
Emission Reduction due to Evap I/M***	52,300 tons	11,100 tons
Cost Effectiveness	\$3500/ton	\$6670/ton

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* Based on the vehicle VMT of 61 non-California ozone non-attainment areas, MOBILE3 fuel consumption model total number of 1978 and newer model year vehicles, MOBILE3 vehicle registration distributions and MOBILE3 projections of the number of carbureted and fuel injected vehicles.

** Fuel recovery credit was determined at \$290.32/ton assuming the recovered emissions were butane. The recovered emissions were determined using MOBILE3 with average July temperatures.

*** Emission reductions were determined using MOBILE3 with ozone design value day temperatures.

program might be implemented. First year benefits from the full centralized evaporative I/M program (Case #1) are 63,000 tons per year VOC (0.9 percent of the total VOC inventory) with a cost effectiveness of $3,350 per ton. The decentralized tampering only program (Case #2) reduced VOC by 12,000 tons per year (0.2 percent of the total VOC inventory) at $4,420/ton. By the year 2010 Case #1 will reduce VOC by 95,000 tons per year (1.2 percent of the total VOC inventory) at $1,790 per ton. In 2010, Case #2 will reduce VOC by 20,700 tons per year (0.3 percent of the total VOC inventory) at $3,430/ton.

Table 6-B-15 repeats the analysis for the year 2010, but assumes volatility control to 9.0 psi in ASTM Class C areas and proportional reductions in ASTM non-class C areas. This affects both the benefits of evaporative I/M and the fuel recovery credit, but does not affect the inspection and repair costs. With these changes in 2010, Case #1 will reduce VOC by 52,300 tons per year (0.7 percent of the total VOC inventory) at $3,500 per ton and Case #2 will reduce VOC by 11,100 tons per year (0.2 percent of the total VOC inventory) at $6,670 per ton.

CHAPTER 7

Analysis of Alternatives: Alcohol Blends

During the past several years commercial fuel has been introduced which consists of gasoline blended with ethanol, methanol, and other alcohols.* Blending an alcohol into gasoline increases the volatility of the final product, making the potential increase in evaporative and exhaust emissions a special concern. However, certain approaches to volatility control could have serious economic impacts on the fuel-alcohol industries, particularly on ethanol blenders. This chapter evaluates alcohol blends separately from straight gasoline and considers the desirability of separate regulatory approaches for alcohol blends.

I. Industry Economics and Blend RVP

The fuel ethanol and methanol industries have developed in ways that give them unique economic characteristics. It is important to view the impact blends have on HC emissions in the light of these characteristics.

A. Gasohol

Gasohol began entering certain fuel markets in the late 1970's with the enactment of a tax credit applicable to the federal gasoline tax. The credit has grown to 6 cents/gallon of gasohol (equivalent to 60 cents/gallon of ethanol) and was the result of dual Congressional desires to reduce U.S. dependence on imported oil and to make use of excess agricultural production (specifically, corn). A number of states have also enacted tax credits ranging from one-half to 14 cents/gallon of gasohol.

New alcohol blends require an EPA waiver in order to be introduced commercially (as provided in Section 211(f) of the Clean Air Act). In 1978, when a waiver was requested for gasohol, the Agency did not act to disapprove the waiver application for gasohol within the statutorily required 180 days and the waiver for gasohol was automatically granted under Section 211(f).

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* For convenience, alcohol blends containing only ethanol are referred to as gasohol. In practice, these blends rarely contain more or less than 9-10 percent ethanol. Any blend containing methanol, even though ethanol may be present as a cosolvent, will be referred to as a methanol blend.

An important result of the automatic approval of the gasohol waiver was that in accordance with the waiver request no constraints were imposed on the volatility of gasohol. This factor has in turn meant a great deal of flexibility for the industry in the gasolines they can use for blending with ethanol. Since final product volatility is not regulated, ethanol blenders have been able to use gasolines that were originally refined as final-use fuels. These fuels are more easily and cheaply obtained than specially-formulated low-RVP base fuels, and the ability to use the standard finished gasoline has continued to play a significant role in the development of the gasohol market. The term "splash blending" is used here to describe this practice of blending alcohols with "final-use" gasoline. The practice of splash blending increases the RVP of gasohol by up to about 1.0 psi as compared to straight gasoline as discussed in Section II.B. of Chapter 2.

Another physical phenomenon which affects the actual volatility effect of gasohol (or any alcohol blend) in the field is called commingling. It occurs when vehicle fuel tanks are intermittently filled with alcohol blends and then with straight gasoline. The RVP of the resulting mixture can be significantly higher than that of the blend or the straight gasoline. At current market levels the effect of commingling is equivalent to an overall increase in in-use blend RVP of about 0.2 psi RVP for those vehicles using some amount of gasohol, as discussed in Section II.B. of Chapter 2.

Section II of Chapter 3 states that nationally, gasohol accounts for about 7 percent of the gasoline market, varying among states (because of different state tax exemptions) from zero to more than 30 percent. About 80 percent of gasohol is sold in Midwest states (that is, close to major corn producing areas).[1]

B. Methanol Blends

Several blends of methanol and gasoline have received EPA waivers permitting their sale at one time or another. The two waivered methanol blends which are expected to be most common are an ARCO blend called "Oxinol" and a DuPont blend. Each blend also includes a higher-alcohol "cosolvent" (e.g., ethanol) to help prevent phase separation in the presence of water. Oxinol is typically 4.75 percent methanol with 4.75 percent tertiary butyl alcohol (TBA). The Dupont blend is 5 percent methanol with 2.5 percent ethanol or another higher alcohol.

Unlike gasohol, these methanol blends are subject to volatility limits as a provision of their EPA waivers. The requirement is that the RVP of the final blend not exceed the current ASTM limits for gasoline.* The volatility limit ensures that evaporative and exhaust emissions from methanol blend-fueled vehicles will not greatly exceed emissions from gasoline-fueled vehicles.

Since adding methanol and a cosolvent to gasoline to produce these blends increases RVP by about 2 psi (see Section II.B. of Chapter 2) and since the RVPs of few gasolines are 2 psi below the ASTM limits, these methanol blends require specially formulated lower-RVP base gasolines. Because of this, methanol cannot be "splash blended" (as defined above).

At a 10 percent local market penetration by methanol blends, the commingling effect would boost the effective RVP for those vehicles using the blends by about 0.7 psi RVP, as discussed in Section II.B. of Chapter 2.

To date, only the ARCO "Oxinol" blend has actually been marketed, achieving a 1.3 percent market share nationwide during 1985 (mostly in the Northeast). Today neither Oxinol nor the DuPont blend is available commercially, in large part because the low price of crude oil has removed much of their economic advantage.

II. Emission Effects of Blend Usage

Several factors interact to affect the evaporative and exhaust VOC emissions of alcohol blends and their effect on urban ozone formation (see Chapter 2, Section II.B. of this report). The analysis in that chapter compares the effect on ozone formation of VOC emissions from vehicle fleets including some alcohol blend use with a gasoline-only fleet at the same RVP. Certain factors would tend to reduce the fleetwide ozone potential of both alcohol blends relative to gasoline, including lower VOC exhaust emission and less photochemically reactive evaporative emissions. However, assuming 10 percent market shares for the blends, other factors such as commingling offset these positive effects. The resulting fleetwide increase or decrease in ozone formation potential between gasoline and either gasohol or methanol blends if RVPs are matched is less than 1 percent.

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* The DuPont blend originally had more stringent requirements which have recently been relaxed (51 FR 39800, October 31, 1986).

The RVP of current gasohol, however, is about 1.0 psi higher than gasoline RVP, as stated above. Because of this, blend-fueled vehicles have significantly higher evaporative emissions than gasoline-fueled vehicles, although their exhaust emissions are slightly lower. The evaporative increase, however, more than offsets the exhaust reduction for both ethanol and methanol blends. The increase in ozone potential of evaporative plus exhaust emissions from a gasohol-fueled vehicle is about 15 to 35 percent (depending on RVP level) compared to gasoline-fueled vehicle emissions. On a fleetwide basis (assuming a 10 percent market penetration by gasohol), the increase in total ozone potential over a gasoline-only fleet would be about 2 to 3 percent. (At a similar market penetration, methanol blends would have about the same fleetwide effect on ozone potential as gasohol.)

III. Effect of RVP Control on Alcohol Blends

A. Effect on Emissions

For each psi that alcohol blend RVP were reduced, essentially the same VOC emission reductions would be achievable as for gasoline. However, gasohol is currently about 1.0 psi RVP higher than gasoline (and methanol blends) as stated above. Thus if gasohol were controlled to the same RVP as gasoline, about 2 to 3 percent additional ozone control would be possible.

B. Effect on Refinery and Distribution Costs

As with emissions, refinery-level costs resulting from alcohol blend RVP control would be similar to gasoline RVP control costs, since reducing RVP would require about the same effort for both final-use gasoline and for gasoline base stocks for alcohol blends.

Costs might be slightly higher (roughly 0.5 cents/gallon) in cases where lower RVP base gasolines were required (as is the case today for methanol blends) because the cost effects of RVP control can become more pronounced at lower RVP levels (see Section III of Chapter 5). Offsetting these higher costs, however, would be the savings to refiners of making use of ethanol's octane value as discussed in Chapter 5, Section III. Currently, much of the octane-enhancing quality of ethanol is "wasted" in a sense. This happens because with splash blending, existing final-use gasolines that already have a sufficient octane rating are blended with ethanol, further increasing octane unnecessarily.

However, if refiners were to produce lower-RVP fuels as blend stock for gasohol, the octane value of those fuels would not need to be as high as for final-use fuels because ethanol would be added. The blending could happen at the refinery or later if the lower RVP, lower octane base fuel were kept segregated during distribution. This ability to take advantage of ethanol's octane value at the refinery would be an economic benefit to refiners because the costs of boosting octane through additives or additional refining would be reduced. The value of this octane savings (discussed in Chapter 5, Section III) would more than make up for the cost of producing the lower-RVP base gasoline.

Despite this ability by refiners to take advantage of ethanol's octane value, a requirement to meet the same RVP as gasoline could introduce new distribution-related costs to gasohol producers. If this cost issue is ignored for the moment, the discussion above indicates that both the emission reductions and refinery-level control costs would be about the same as those associated with gasoline RVP control -- and thus the cost per ton of RVP control for alcohol blends would be almost exactly the same as for gasoline. This means that absent the distribution effects, cost effectiveness (i.e., cost per ton) is not a deciding factor in determining whether to treat blends differently from gasoline; absent such effects, EPA would control all fuels to the same RVP level.

In reality, however, a requirement that gasohol meet gasoline RVP limits would create serious new problems. As stated above, gasoline is subject to non-binding ASTM volatility limits, methanol blend RVPs are controlled to typical gasoline levels, but gasohol is free from any administrative volatility constraints. The gasohol industry has relied heavily on their ability to market their product at a higher RVP than the other fuels, and hence to splash blend ethanol with gasoline.

If volatility controls required gasohol to meet the same limits as gasoline, the gasohol industry might be unable to obtain sufficient amounts of special reduced-RVP gasoline stock; costs could be prohibitive in any case, largely because separate distribution and storage facilities would be needed in order to keep the special stock segregated from higher RVP fuels. EPA contractors have conducted three studies of this economic impact [2,3,4], but the dependence of the result on local factors such as number of storage tanks and their current availability makes the task of developing reliable estimates very difficult. Nevertheless, it is clear that a major impact on gasohol sales and the industry as a whole is possible.

Another factor that could potentially affect gasohol distribution should be mentioned: The state of Colorado is considering a carbon monoxide emission control strategy that could mandate the use of oxygenated fuels during the winter months. If enacted, this program could expand gasohol's current market. In addition, since distribution of low-octane low-RVP gasoline to Colorado gasohol blenders would probably increase, a transition to a summertime gasohol RVP control program could conceivably be less costly with these wintertime oxygenated fuel requirements in place.

IV. Gasohol Control Options

Without the potential for major costs to the gasohol industry, EPA would simply require that gasohol meet the same RVP standards as gasoline (i.e., the same requirement as for methanol blends). However, because of the public policy concerns about the importance of a gasohol industry in the U.S., additional options have been developed and evaluated. In light of the conclusions about gasohol, two options that could apply to methanol blends are also considered.

Each of the following gasohol control options were considered:

Option 1. Continue the existing gasohol exemption from RVP control.

Option 2. Instead of a total exemption, establish a gasohol RVP standard 1.0 psi higher than that for gasoline (i.e., a 1.0 psi RVP allowance).

Option 3. Require gasohol RVP to equal the RVP of straight gasolines.

a. Apply this requirement nationwide.

b. Apply requirement only to gasohol sold in ozone non-attainment areas; provide a 1.0 psi RVP allowance in attainment areas.

c. Delay requirement until 1993; provide a 1.0 psi RVP allowance in the interim.

The following paragraphs discuss each gasohol option.

Option 1. Administratively, this option represents the current situation--gasohol blenders could continue to use commercial gasolines for base stock. For this reason, it is unlikely that the ethanol industry would experience any adverse economic impact.

However, if EPA required gasoline refiners to significantly reduce the volatility of their fuels refiners would have surpluses of certain very high RVP gasoline components and a desire to market them. If gasohol continued to have no RVP restrictions, it is very likely that more of these very high RVP components would be used as gasohol base stock, a current but not yet widespread practice. Although gasohol today averages 1.0 psi RVP above gasoline RVP or less, this practice could boost gasohol RVP much higher, with an associated increase in VOC emissions. Another result would be to make ethanol more attractive and thus more valuable as a gasoline extender, possibly increasing gasohol usage. The loss of emission control associated with a gasohol RVP exemption under an in-use RVP control program would probably be even greater than what would occur under the similar Option 2 below. Gasohol industry representatives are not strongly advocating this option.[5]

Option 2. A 1.0 psi RVP allowance for gasohol, like the exemption, would continue to allow splash-blending (ethanol adds up to 1.0 psi to gasoline RVP) and hence would not economically threaten the gasohol industry. Unlike the exemption, the fixed allowance would eliminate the ability to market very high RVP gasoline as gasohol base stock.

The emissions impact of allowing a 1.0 psi RVP disparity between gasoline and gasohol, as with the total RVP exemption, is substantial. We estimate that at least 2 to 3 percent of the potential fleetwide ozone control achievable in the year 2010 by reducing Class C gasoline RVP to 9.0 psi could be lost because of gasohol's higher RVP (see Section II above). In areas with high gasohol market shares, the emissions effect would be greater -- a very significant 2 percent of all Chicago VOC emissions, for example. Appendix 7-A contains a detailed derivation of the effect of the gasohol RVP allowance on the Chicago VOC inventory.

Option 3. Under this option EPA would require that gasohol's RVP be no higher than the RVP of in-use gasolines. Environmentally, this approach is most logical since emissions are a function of RVP and all gasolines and blends would meet the same RVP standard. Thus, gasohol use under this option would add very little to evaporative and vehicle exhaust emissions and their effect on ozone production as compared to a fleet using only straight gasoline.

However, as discussed earlier, requiring gasohol to meet the same RVP limits as gasoline would create serious economic burdens for the gasohol industry. On the other hand, refiners could take advantage of ethanol's octane value, as discussed above, which might make gasohol cheaper.

a. Implementing Option 3 nationwide simultaneously with new gasoline volatility controls would mean that the impact of distribution-related costs would be felt by the gasohol industry immediately. If measures are available to the industry which could cushion the effect, there would be very little time to implement them.

b. Another approach might be to implement Option 3 only in ozone non-attainment areas. The adverse effects of requiring in-use gasohol RVP to equal gasoline RVP might occur, but now only in non-attainment areas. Outside non-attainment areas, the program under this option would have the characteristics described above for Option 2 (1.0 psi RVP allowance for gasohol), in effect providing a continued but more limited splash-blending market for gasohol producers.

This kind of approach would indeed target emission control primarily in the areas that need it most, eliminating some of the environmental concerns associated with Option 2 above. There would remain the concern that HC emissions would still be higher in attainment areas, where emission reductions do have some value (see Section I of Chapter 6.) In any case, it does not appear that such targeting would sufficiently relieve the economic burden on the gasohol industry. According to the Ad Hoc Ethanol Committee[1] the reason is that the widespread nature of the ozone problem results in over half of the gasohol market being within current non-attainment areas. It is unlikely that gasohol market penetration could be increased in attainment areas enough to make up the difference. Thus, if prohibiting splash blending gasohol in non-attainment areas would effectively eliminate that market, as the industry claims, then the nationwide gasohol market would be severely reduced, resulting in increased production costs, higher prices or lower profits margins, and still greater reduced sales.

Finally, as with any policy which is geographically targeted, issues of competition are likely to arise among businesses near the boundaries. On one side of a boundary, service stations might be able to obtain gasohol to sell, and on the other side, not.

c. A third approach would delay Option 3 until 1993, the year in which the Federal tax credit for gasohol is set to end. The effect of this alternative would be that the additional emissions as well as the ability to splash blend associated with Option 2 (1.0 psi RVP allowance) would occur from the date of implementation of gasoline RVP control through December 31, 1992 (essentially until May 1993, since RVP control is not being considered during non-summer months). After that, gasohol RVP would need to match gasoline RVP, with the same ramifications we described for Option 3a above.

This option would allow ethanol producers about four years to change their marketing strategy (i.e., develop sources of low-RVP, low-octane base gasoline stock). Since splash-blended gasohol is not expected to be profitable without the Federal tax credit (unless perhaps crude oil prices exceed their previous highs), the application of the RVP limit after the tax credit expires will have little economic impact. This option would also allow time for Congress to comprehensively review the issues of RVP, the gasohol tax credit, and the overall national economic policy toward gasohol.

V. Methanol-Blend Control Options

Methanol blends have not historically received the same degree of public attention and special incentives that gasohol has. One example is the tighter volatility requirements that are part of all EPA methanol blend waivers (e.g., ARCO "Oxinol" and the DuPont blend, as discussed earlier). These waiver requirements have meant that, from the start, methanol blenders have expected to operate using special low-RVP base gasolines as a base stock. A 1.0 psi RVP allowance for methanol blends, while it would be a substantial benefit to that industry, is clearly not key to preserving any existing market for these products; in fact, none are sold at this time. (Methanol is established as a feedstock in the chemical industry but not yet as a gasoline blend stock; fuel-grade ethanol, in contrast, has no established market except gasohol).

However, if EPA were to select Option 2 or Option 3c for gasohol, which would establish a permanent or temporary volatility allowance for gasohol, it raises the issue of whether to also provide a similar RVP allowance for methanol blends. Increased emissions would certainly result if methanol blends were marketed at a 1.0 psi higher RVP than gasoline.

References (Chapter 7)

1. Letter from B. Direnfeld, Ad Hoc Ethanol Committee, to C. Gray, EPA, dated June 26, 1986.

2. "The Effect of Gasoline Volatility Control on Selected Aspects of Ethanol Blending," Jack Faucett Associates, November 4, 1985.

3. "The Effect of Gasoline Volatility Control on Methanol and Ethanol Blend Usage," Draft Final Report, Jack Faucett Associates, September 12, 1986 .

4. "The Impact of Volatility Regulations on the Fuel-Grade Ethanol Industry," Sobotka & Co., Inc., March, 1987.

5. Letter from B. Direnfeld, Ad Hoc Ethanol Committee, to C. Gray, EPA, dated August 15, 1986.

Appendix 7-A

Effect of Gasohol RVP Allowance on Chicago VOC Inventory

In Chapter 7, the statement is made that if gasohol (90 percent gasoline and 10 percent ethanol) is granted a 1.0 psi RVP allowance over the controlled volatility level of gasoline, the result could be an increase of approximately two percent in the Chicago emissions inventory, relative to the case where gasohol must meet the same volatility limit as gasoline. This appendix documents the derivation of that estimated increase. Chicago was chosen as the area to examine because it is a densely populated city in violation of the ozone NAAQS and its gasohol market fraction was the greatest (in September 1985) of the 61 urban non-California ozone non-attainment areas examined in the volatility analyses.

The first step in deriving these estimates is the calculation of motor vehicle non-methane hydrocarbon (NMHC) emission factors. Separate emission factors (EFs) were modeled for exhaust, evaporative, and refueling NMHC emissions, using EPA's in-house version of MOBILE3. The in-house version of the MOBILE3 model was used to model EFs on a city-specific basis. A more detailed discussion of the use of in-house MOBILE3 to model NMHC EFs on city-specific basis is contained in Chapter 3 (Environmental Impact). The remainder of this discussion will focus on the EFs modeled for the Chicago area.

The exhaust, evaporative, refueling, and total NMHC EFs modeled for Chicago are presented in an attachment to this memorandum. The city specific data inputs used in the calculation of these EFs were temperatures (the maximum and minimum temperatures recorded in Chicago on the date that the 1982-84 ozone design value was recorded, July 15, 1983); in-use fuel volatility, expressed in terms of Reid Vapor Pressure (RVP); and the market share of gasohol (gasoline/ethanol blend). In-use RVP data from July 1985, when the fuel volatility survey was conducted, and gasohol market share data from September 1985, which was the most recent available at the time of this analysis, were used in the modeling of EFs for all of the projection years.

The temperature, volatility, and gasohol market fraction data used to model Chicago area EFs are summarized below:

• Temperature:	Max 95°F (35°C) Min 77°F (25°C) (July 15, 1983)
• In-use RVP:	11.9 psi (July 1985)

- Gasohol market
  fraction: 29.9% (Sept 1985)

In modeling the NMHC EFs for each city, the effective volatility (RVP) of the fuel in a given vehicle using gasohol was assumed to be 0.2 psi greater than that of straight gasoline, as a result of commingling of gasohol and gasoline in the vehicle fuel tank. This 0.2 psi offset assumes that gasoline and gasohol are required to meet the same volatility (RVP) limit. If it is assumed that gasohol will be permitted a 1.0 psi allowance (exceedance) from the controlled volatility level of gasoline, which would permit the blending of gasohol from the same gasoline pool, then the total offset between the RVPs of gasoline and gasohol would be 1.2 psi. The Chicago area EFs presented in the attachment thus include two sets of EFs for each RVP control level: one labeled "offs 1.2," reflecting the case where gasohol has a 1.0 psi allowance above the RVP limit for gasoline, and the other labeled "offs 0.2," reflecting the case where gasohol is required to meet the same RVP limit as gasoline.

All of the EFs shown in the attachment are for "all vehicles," meaning that they incorporate emission rates for all regulated vehicle classes (gasoline and diesel light-duty vehicles and trucks and heavy-duty vehicles), appropriately weighted by their fractions of vehicle miles traveled (VMT). These EFs do not include emissions from off-highway vehicles (e.g., construction equipment, boat engines), which are not regulated in terms of emissions and are not included in MOBILE3.

Since other factors determining total emissions from mobile sources (such as fleet composition or VMT mix) would not be affected by a possible RVP allowance for gasohol, comparison of the Chicago area total NMHC EFs calculated with and without this allowance provides a good indication of the emissions increases that could occur if such an allowance were implemented. By combining this information with the size of the regulated mobile source inventory as a fraction of the total NMHC inventory, an estimate of the impact of the allowance on the total inventory was obtained.

The cases examined were for projection years 1988 and 2010; 1988 is the earliest year that RVP limits could be imposed, while 2010 is the latest year used in the analyses. The control RVP levels examined were 10.5 and 11.5 psi for 1988, and 8.0, 9.0, 10.5 and 11.5 psi for 2010.

Inventory projections were run for the Chicago area for each of seven projection years and eight control RVP levels. From these projections, the split of the total Chicago area NMHC inventory between regulated mobile sources and all other sources was determined. Multiplying the fractional increase in the emission factor by the fraction of the total inventory represented by the regulated mobile sources yielded the estimated inventory increases. This is summarized in Table 7-A-1.

The greatest increase (2.2 percent) is seen in 1988 at a control RVP level of 11.5 psi. The much lower estimates of this increase in 2010 are primarily due to the fact that mobile sources will be a much smaller fraction of the total inventory as the full effects of existing mobile source emission control programs are realized.

Table 7-A-1

Chicago EF and Inventory Data

Year	RVP (psi)	Total Emission Factor (g/mi) No Allowance	Total Emission Factor (g/mi) 1.0 psi Allowance	Incr in EF (%)	On-Highway Mobile Sources as Fraction of Total Inventory (%)	Increase in Total Inventory Due to 1.0 psi Allowance (%)
1988	10.5	3.35	3.50	4.5	28.8	1.3
	11.5	3.85	4.12	7.0	31.9	2.2
2010	8.0	1.15	1.20	4.3	13.4	0.6
	9.0	1.19	1.24	4.2	13.6	0.6
	10.5	1.27	1.32	3.9	14.3	0.6
	11.5	.33	1.41	6.0	14.9	0.9

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